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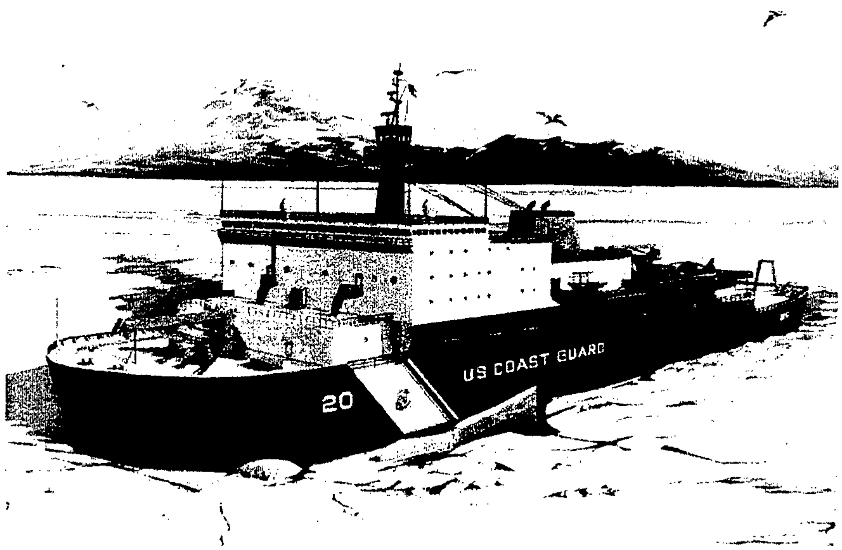
USCGC HEALY (WAGB 20)
Results of Performance and Special Trials



by
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14. ABSTRACT

Performance and Special Trials consisting of standardization, fuel performance, tactical, and maneuvering trials were conducted on USCGC HEALY (WAGB 20) during builder's sea trials to evaluate the hydrodynamic performance of the ship. The trials were conducted in the Gulf of Mexico off the coast of Louisiana from 23 through 31 August 1999.

Standardization and fuel performance trials results showed that HEALY achieved the maximum powering conditions of an average shaft speed of 148.4 rpm, a total shaft torque of 725,000 lbf-ft (983,000 N-m), a total shaft power of 20,500 hp (15,300 kW), and a total fuel consumption of 1,005 gal/hr (3,806 liters/hr) with a ship speed of 16.40 knots. The trials were accomplished at a displacement of 16,412 LT (18,152 tonnes).

For ship speeds between 8 and 16.8 knots (the minimum and maximum speeds tested during the tactical trials), HEALY has a tactical diameter of 3.1 ship lengths or less when using a rudder angle of 35 degrees. Results of the tactical trials shows that HEALY has similar tactical dimensions whether turning to starboard or to port.

The maneuvering trials consisted of lateral stability, horizontal overshoots, and low speed controllability trials. The lateral stability trials results show that HEALY is directionally stable. The horizontal overshoot results also indicate that HEALY responds similarly using right and left rudder. Results of the low speed controllability trials indicate that the controllability of HEALY is significantly reduced at speeds below 6 knots.

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ABSTRACT

Performance and Special Trials consisting of standardization, fuel performance, tactical, and maneuvering trials were conducted on USCGC HEALY (WAGB 20) during builder's sea trials to evaluate the hydrodynamic performance of the ship. The trials were conducted in the Gulf of Mexico off the coast of Louisiana from 23 through 31 August 1999.

Standardization and fuel performance trials results showed that HEALY achieved the maximum powering conditions of an average shaft speed of 148.4 rpm, a total shaft torque of 725,000 lbf-ft (983,000 N-m), a total shaft power of 20,500 hp (15,300 kW), and a total fuel consumption of 1,005 gal/hr (3,806 liters/hr) with a ship speed of 16.40 knots. The trials were accomplished at a displacement of 16,412 LT (18,152 tonnes).

For ship speeds between 8 and 16.8 knots (the minimum and maximum speeds tested during the tactical trials), HEALY has a tactical diameter of 3.1 ship lengths or less when using a rudder angle of 35 degrees. Results of the tactical trials shows that HEALY has similar tactical dimensions whether turning to starboard or to port.

The maneuvering trials consisted of lateral stability, horizontal overshoots, and low speed controllability trials. The lateral stability trials results show that HEALY is directionally stable. The horizontal overshoot results also indicate that HEALY responds similarly using right and left rudder. Results of the low speed controllability trials indicate that the controllability of HEALY is significantly reduced at speeds below 6 knots.

ADMINISTRATIVE INFORMATION

Naval Surface Warfare Center, Carderock Division (NSWCCD), Code 5200, was tasked by Naval Sea Systems Command (NAVSEA) PMS 373 to conduct Performance and Special Trials (P&ST) on USCGC HEALY (WAGB 20). This work was authorized by Work Request N0002497WR20762-AA. The trials discussed in this report were conducted by NSWCCD representatives and were funded under Work Unit 5200-020.

INTRODUCTION

USCGC HEALY is a multi-mission icebreaking research ship capable of effectively performing operations satisfying a broad spectrum of scientific and icebreaking requirements in all polar regions. HEALY was named in honor of Captain Michael A. Healy, distinguished Commanding Officer of the U.S. Revenue Cutter BEAR from 1886 to 1895. Captain Healy was most notable as the foremost seaman and navigator of his time in the Bering Sea and Alaskan Arctic regions while commanding the BEAR.

The acquisition of HEALY was a joint effort between the U.S. Coast Guard and the U.S. Navy. Avondale Industries was awarded the construction contract on 15 July 1993.

The source of propulsion power for HEALY is four 7200 kilowatt diesel generator sets. The outputs of these generators are connected through a 6600 VAC, 60 Hz, 3 phase common bus distribution system to form a "central power plant". The "central power plant" routes the required electrical power to two fully reversing, variable speed, AC synchronous motors to power the port and starboard main propulsion shafts.

Fully automated systems provide control for the ship and the machinery plant. The Main Ship Control Console (MSCC) consists of the Integrated Bridge System that is comprised of the Integrated Navigation System, the Steering Control System, and the Electronic Chart Display Information System. Machinery plant control is provided in the Engineering Control Center through the Machinery Plant Control and Monitoring System (MPCMS). MPCMS provides control, monitoring, alarm, and reporting functions for all propulsion and auxiliary equipment.

Standardization, fuel economy, tactical, and maneuvering trials were conducted on USCGC HEALY (WAGB 20) during builder's sea trials in the Gulf of Mexico off the coast of Louisiana from 23 through 31 August 1999. The objective of the trials was to determine the hydrodynamic characteristics of the ship. The characteristics determined during the trials are presented in this report.

Table 1 lists the principal characteristics of the ship, propulsion system, and propellers.

TRIALS INSTRUMENTATION

The instrumentation for the trials was installed during two separate time periods in an effort to support various shipbuilder trials events. Torque and shaft speed measurement equipment was installed on HEALY during the period 15-21 July 1999. This equipment was needed to determine shaft torque, shaft speed, and shaft power during the initial shipyard underway periods referred to as "River Runs". The remainder of the instrumentation package was installed during the period 26-30 July 1999. Signal conditioning equipment was installed in the Motor Room, the Generator Room, and the Boiler Room. Outputs from the conditioning equipment were connected to the ship's fiber optic data network for transmission to the recording equipment located in the Chart Room. The instrumentation used during the trials is described in greater detail in Appendix A.

Table 1. USCGC HEALY (WAGB 20) principal ship, propulsion system, and propeller characteristics.

Ship Characteristics	
Length overall (L_{OA})	420.0 ft (128.02 m)
Length on waterline (L_{OA})	401.61 ft (122.41 m)
Length between perpendiculars (L_{PP})	396.50 ft (120.85 m)
Beam, (B)	82.00 ft (24.99 m)
Beam, waterline (B_{wl})	79.97 ft (24.37 m)
Design Draft	29.25 ft (8.92 m)
Design Displacement	16,267 LT (17,991 tonnes)
Propulsion System Characteristics	
Propulsion plant	Diesel Electric, AC / AC Cycloconverter
Generators	4 Sultzer 12Z AU40S
Drive motors	2 Synchronous, 11.2MW
Design shaft power	30,000 hp (22,380 kW)
Design shaft speed	
Open ocean	168 rpm
Icebreaking	130 rpm
Bow thruster	2200 hp (1641 kW)
Propeller Characteristics	
Number of propellers	2
Direction of rotation	Outboard Top
Number of blades	4
Propeller diameter	16.0 ft (4.877 m)
Pitch ratio at 0.7R	0.934
Expanded Area Ratio	0.68
Chord length at 0.7R	7.789 ft (2.374 m)
Maximum thickness at 0.7R	0.406 ft (0.124 m)
Hub diameter	5.584 ft (1.702 m)

TRIALS CONDITIONS

The ship's hull and propellers must be in a clean condition at the time the P&ST is accomplished. Environmental conditions must also be within specified limitations in order for the trials results to be representative of the performance of the ship itself and not be biased in some manner by the effects of unfavorable weather conditions.

HULL AND PROPELLER CONDITIONS

NSWCCD representatives conducted a hull and propeller roughness survey on HEALY during the period 26-28 January 1999. HEALY was in dry-dock at Avondale shipyard at the time of the survey and access to the hull was accomplished with a "cherry-picker" provided by the shipyard. Access to the port and starboard propellers was obtained by using scaffolding previously installed by Avondale shipyard.

Hull and propeller roughness data were collected with a British Ship Research Association (BSRA) Mark II Roughness Analyzer. The BSRA gauge was used to collect peak-to-trough roughness measurements at representative locations on the surface of the hull, the rudders, and the propellers. The gauge measures the maximum peak-to-trough height of the surface texture in micrometers (μm) for fifteen 50 millimeter sample lengths. The roughness reading for one data length is the average of 15 sample lengths; this is equivalent to a total length of 750 millimeters of surface area. The results of the roughness survey are shown in Table 2.

The ship was re-launched into the Mississippi River at Avondale on 2 February 1999 and remained there until the trials were conducted. The relatively large current and the lack of visibility in the Mississippi River precluded a hull and propeller inspection just prior to the Performance Trials. Due to the strong current and the fresh-water river it is assumed that minimal marine growth would have occurred between the January hull and propeller survey and the August trials. The underwater hull and the propeller measurements are therefore considered to be representative of the condition of the ship at the time of the trials.

Table 2. USCGC HEALY (WAGB 20) hull and propeller roughness survey measurements, 26-28 January 1999.

Hull Locations	Average Roughness (μm)	Skeg and Rudder Locations	Average Roughness (μm)	Propeller Locations	Average Roughness (μm)
Frame 16	131	Skeg - Port	266	Propeller Blade 1 - Port	29
Frame 48	168	Skeg - Stbd	244	Propeller Blade 2 - Port	23
Frame 100	240	Rudder - Port	436	Propeller Blade 1 - Stbd	26
Frame 136 (between skegs)	201	Rudder - Stbd	372	Propeller Blade 2 - Stbd	28

ENVIRONMENTAL CONDITIONS

Builder's sea trials were conducted on HEALY from 23 through 31 August 1999 in the Gulf of Mexico off the coast of Louisiana. Environmental conditions observed during the performance trials portion of the builder's trials are shown in Table 3. Sea states during the trials were ideal and ranged between 0 and 1. During the trials the true wind speed averaged less than 12 knots and was generally from a westerly direction. These conditions were well within the acceptable limits of sea-state 3 and a true wind speed of 20 knots.

Prior to the beginning of the trials, HEALY was ballasted to achieve an even trim with a forward and aft draft of 29.25 ft. Seawater temperature and specific gravity were measured to be 88°F and 1.020 for both days. Compensating for seawater temperature and specific gravity, the ship displacement for the trials was determined to be 16,412 LT (18,152 tonnes).

Table 3. USCGC HEALY (WAGB 20) trials conditions.

Date	25 August 1999	26 August 1999
General Trial Location	Gulf of Mexico	Gulf of Mexico
Latitude	27.0 N	26.6 N
Longitude	89.9 W	89.9 W
Displacement	16,412 LT (18,152 tonnes)	
Water Depth	greater than 1000 fathoms	
Water Temperature	88° F (31° C)	
Specific Gravity	1.020	
True Wind Speed	7 - 12 knots	5 - 7 knots
True Wind Direction	217° - 336°	240° - 310°

STANDARDIZATION AND FUEL ECONOMY TRIALS

Standardization and fuel economy trials were conducted on HEALY on 25-26 August 1999 during builder's sea trials in the Gulf of Mexico. The general ship and environmental conditions for the period are shown in Table 3. All of the speed/power conditions except the 16.4 knots (148 rpm) condition were tested on 25 August. The 16.4 knots (148 rpm) condition was conducted on 26 August. Propulsion plant limitations during the trials prevented the completion of standardization runs with a shaft speed greater than 148 rpm. The propulsion system was unable to sustain powering conditions long enough to accurately measure speed, power, and fuel consumption for three separate runs. However, the approach data measured for the deceleration run from the initial condition of Ahead 100% were determined to be steady and long enough in duration to accurately represent the ship's performance at full power to complete the standardization trials. A drift-corrected ship speed was calculated using the method described in the ensuing section titled "Acceleration and Deceleration Trials."

As shown in Table 3, environmental conditions are considered to have been excellent throughout the standardization and fuel economy trials. Based on the speed measurements for the reciprocal runs, the local ocean currents averaged 1.2 knots on 25 August and 0.5 knots on 26 August. Data obtained during these two days of testing are considered to be representative of the performance characteristics of HEALY.

STANDARDIZATION AND FUEL ECONOMY TRIALS PROCEDURES

The standardization and the fuel economy trials were accomplished concurrently. In order to combine these two tests, the duration of each standardization run was increased from three minutes (typical for standardization runs) to six minutes. The length of each run was doubled to increase the amount of fuel consumed during each run and thus improve the accuracy of the fuel consumption measurement. A diagram of the typical path for a standardization (fuel performance) run is shown in Figure 1. The commands and actions used to conduct the trials are defined as follows:

STANDBY: Steady approach conditions have been established.
One minute to COMEX.

COMEX: Commence data acquisition. Maintain steady conditions.
One minute to EXECUTE.

EXECUTE: Execute the run. Maintain steady conditions.
Acquire data for 6 minutes.

FINEX: Terminate the run and data acquisition.
Ship conducts Williamson turn to prepare for next run.

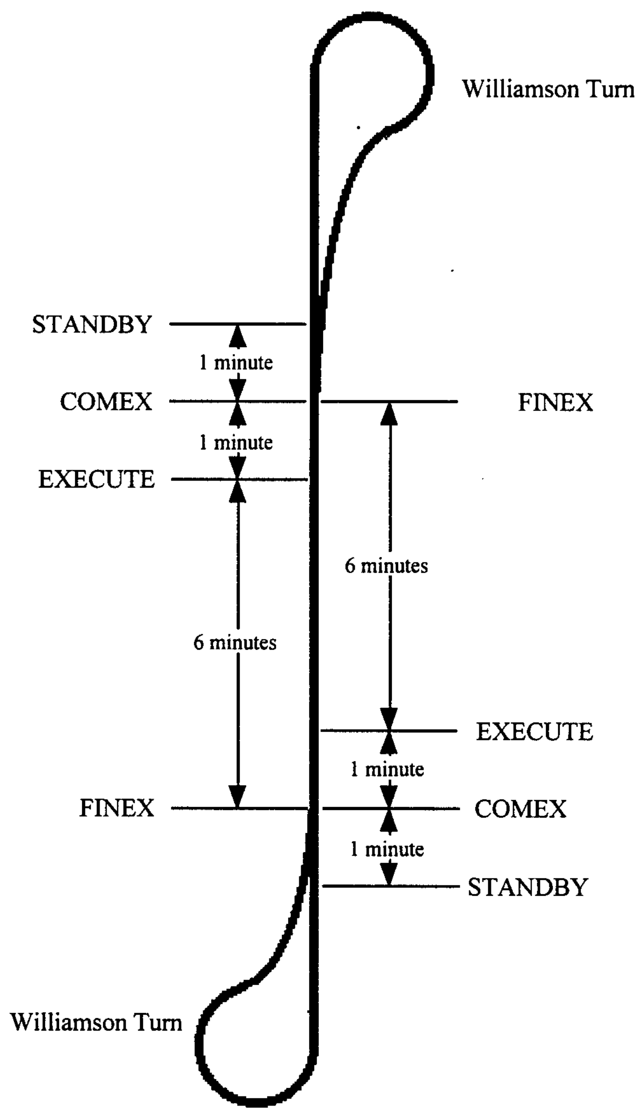

Fig. 1. Typical path of ship during standardization trials.

STANDARDIZATION TRIALS RESULTS

The results of the standardization trials are shown in Figures 2-6 and Tables 4-11. The maximum speed/power conditions achieved on HEALY during the standarization trials were as follows:

Ship Speed	16.40 knots
Average Shaft Speed	148.4 rpm
Total Shaft Torque	725,000 lbf-ft (983,000 N-m)
Total Shaft Power	20,500 hp (15,300 kW)
Total Fuel Consumption	1,005 gal/hr (3,806 liters/hr)
Displacement	16,412 LT (18,152 tonnes)

As discussed previously, the approach data for the deceleration run with the initial condition Ahead 100% were considered acceptable for use in completing the standardization trials. The conditions achieved on HEALY during this run were as follows:

Ship Speed	17.50 knots
Average Shaft Speed	160.0 rpm
Total Shaft Torque	846,000 lbf-ft (1,147,000 N-m)
Total Shaft Power	25,800 hp (19,200 kW)
Total Fuel Consumption	1,190 gal/hr (4,505 liters/hr)
Displacement	16,412 LT (18,152 tonnes)

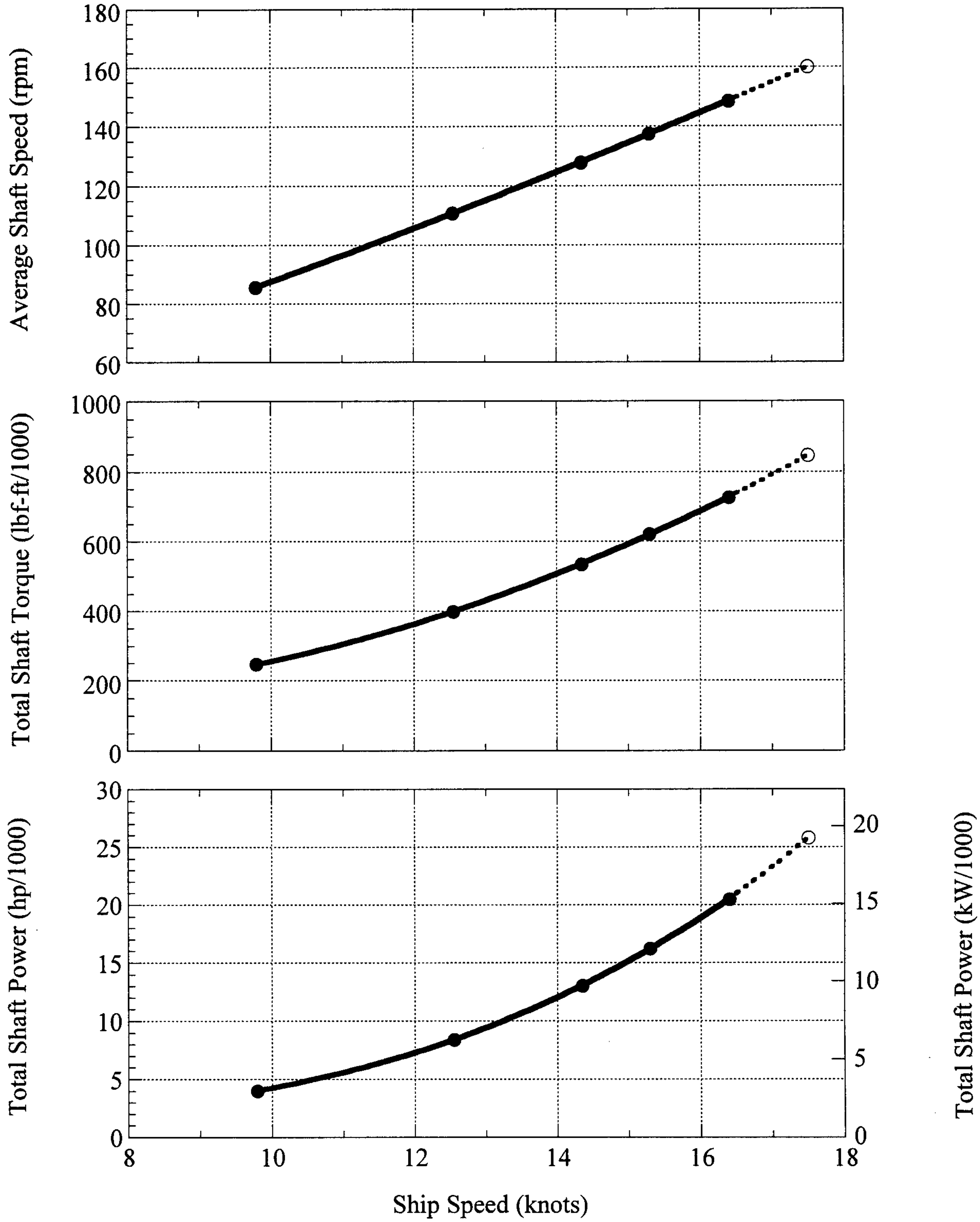

Fig. 2. USCGC HEALY (WAGB 20) standardization trials results, shaft power, shaft torque, and shaft speed versus ship speed, 16,412 LT (18,152 tonnes), 25-26 August 1999.

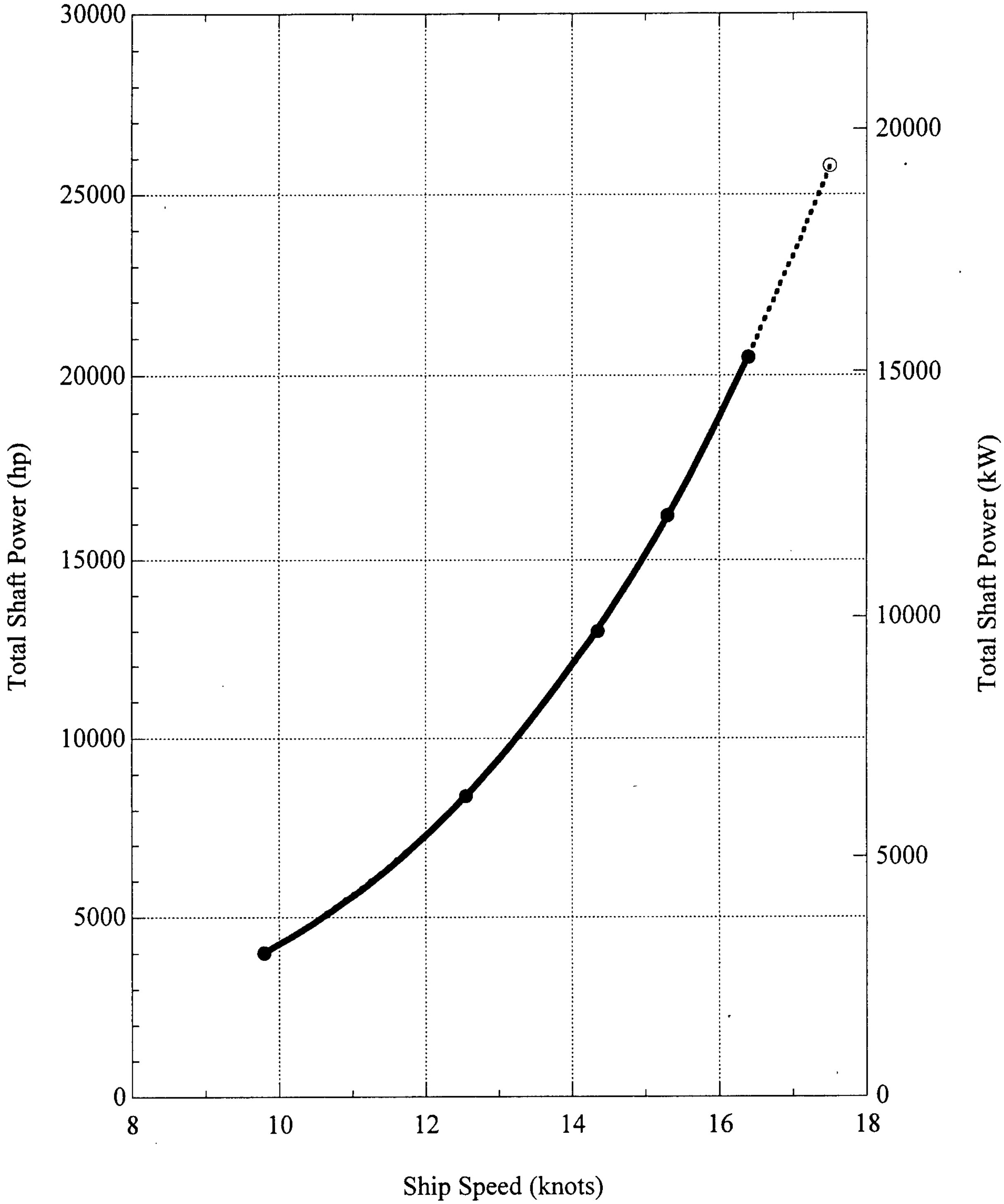

Fig. 3. USCGC HEALY (WAGB 20) standardization trials results, shaft power versus ship speed, 16,412 LT (18,152 tonnes), 25-26 August 1999.

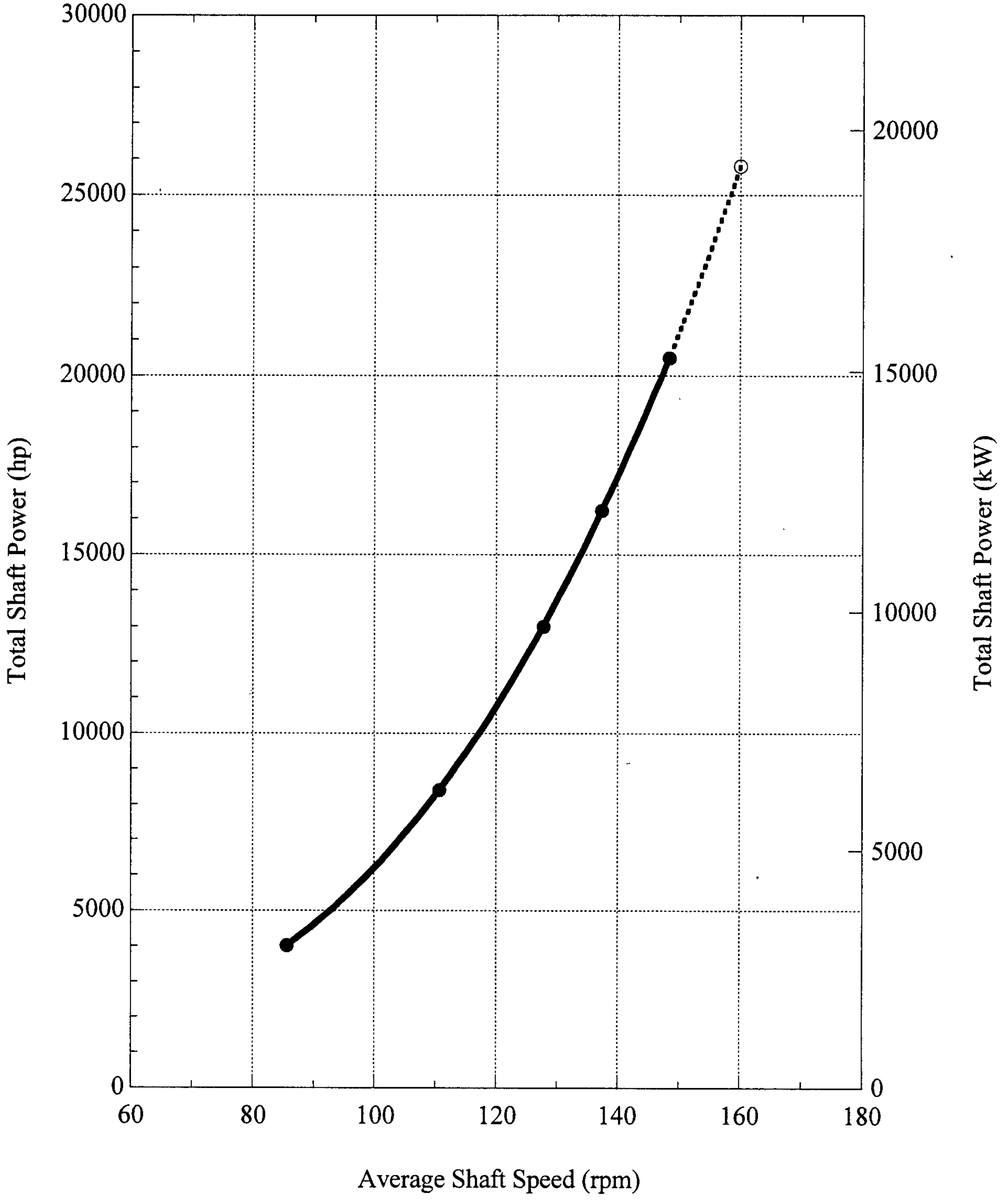

Fig. 4. USCGC HEALY (WAGB 20) standardization trials results, shaft power versus average shaft speed, 16,412 LT (18,152 tonnes), 25-26 August 1999.

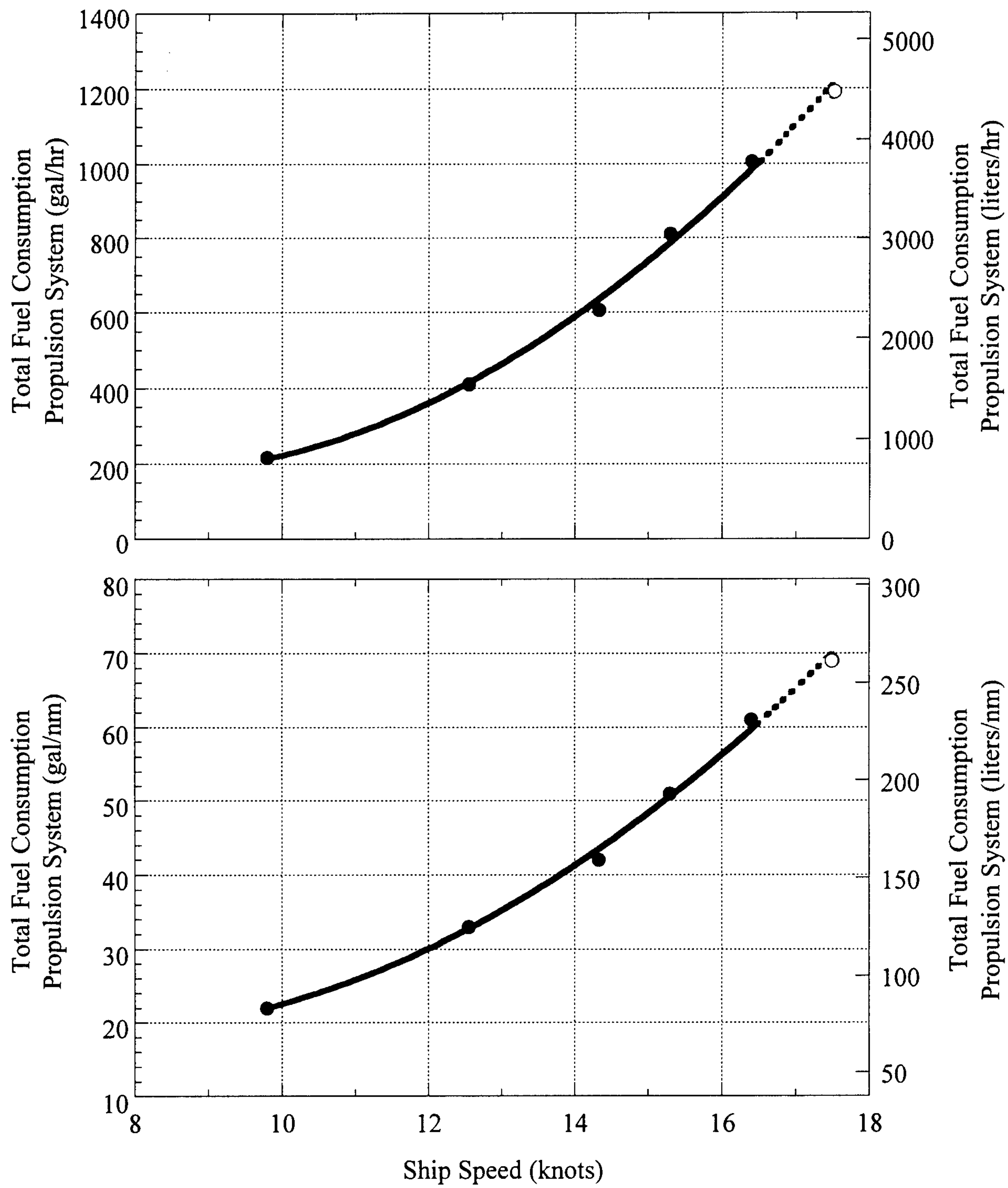

Fig. 5. USCGC HEALY (WAGB 20) standardization trials results, total fuel consumption for the propulsion system versus ship speed, 16,412 LT (18,152 tonnes), 25-26 August 1999.

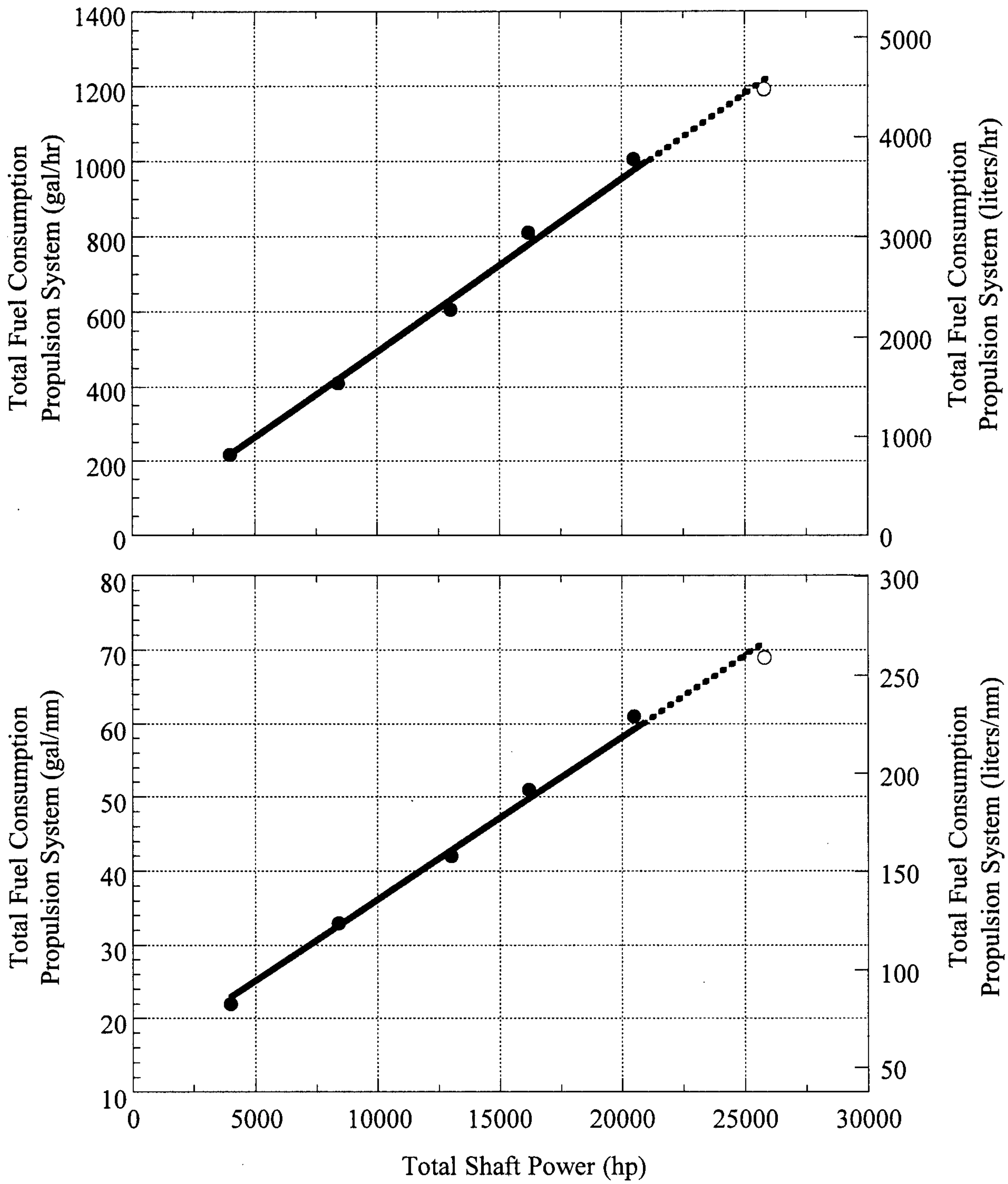

Fig. 6. USCGC HEALY (WAGB 20) standardization trials results, total fuel consumption for the propulsion system versus shaft power, 16,412 LT (18,152 tonnes), 25-26 August 1999.

Table 4. USCGC HEALY (WAGB 20) standardization trials results summary, 16,412 LT, 25-26 August 1999, US customary units.

Run Number	Ship Speed (knots)	Shaft Speed Average (rpm)	Shaft Torque Total (lbf-ft/1000)	Shaft Power Total (hp/1000)	Propulsion Plant Generators (online)	Fuel Consumption Propulsion Only ** Total (gal/hr)
1000N	8.70	85.9	245	4.0	3	218
1010S	10.95	85.2	248	4.0	3	215
1020N	8.60	85.9	246	4.0	3	215
Average	**9.80**	**85.6**	**247**	**4.0**	**3**	**216**
1030S	13.70	110.5	399	8.4	3	410
1040N	11.40	110.7	398	8.4	3	410
1050S	13.70	110.7	399	8.4	3	410
Average	**12.55**	**110.7**	**399**	**8.4**	**3**	**410**
1060N	13.10	127.8	534	13.0	3	608
1070S	15.60	127.8	534	13.0	3	605
1080N	13.00	127.9	535	13.0	3	605
Average	**14.33**	**127.8**	**534**	**13.0**	**3**	**606**
1090S	16.55	137.5	620	16.2	4	812
1100N	14.00	137.4	621	16.2	4	810
1110S	16.65	137.5	620	16.2	4	808
Average	**15.30**	**137.4**	**620**	**16.2**	**4**	**810**
1130S	16.75	148.5	724	20.5	4	1004
1132N	16.10	148.4	725	20.5	4	1005
1140S	16.70	148.5	726	20.5	4	1008
Average	**16.40**	**148.4**	**725**	**20.5**	**4**	**1005**
*3330**	*17.50*	*160.0*	*846*	*25.8*	*4*	*1190*

* *extracted from approach data for deceleration run from 100% ahead*
** *based on 2680hp (2MW) hotel load*

Table 5. USCGC HEALY (WAGB 20) standardization trials results summary, 18,152 tonnes, 25-26 August 1999, metric units.

Run Number	Ship Speed (knots)	Shaft Speed Average (rpm)	Shaft Torque Total (N-m/1000)	Shaft Power Total (MW)	Propulsion Plant Generators (online)	Fuel Consumption Propulsion Only ** Total (liters/hr)
1000N	8.70	85.9	333	3.0	3	825
1010S	10.95	85.2	336	3.0	3	816
1020N	8.60	85.9	333	3.0	3	812
Average	**9.80**	**85.6**	**334**	**3.0**	**3**	**817**
1030S	13.70	110.5	541	6.3	3	1554
1040N	11.40	110.7	540	6.3	3	1552
1050S	13.70	110.7	541	6.3	3	1553
Average	**12.55**	**110.7**	**541**	**6.3**	**3**	**1553**
1060N	13.10	127.8	725	9.7	3	2302
1070S	15.60	127.8	723	9.7	3	2289
1080N	13.00	127.9	725	9.7	3	2291
Average	**14.33**	**127.8**	**724**	**9.7**	**3**	**2293**
1090S	16.55	137.5	840	12.1	4	3074
1100N	14.00	137.4	842	12.1	4	3065
1110S	16.65	137.5	840	12.1	4	3060
Average	**15.30**	**137.4**	**841**	**12.1**	**4**	**3066**
1130S	16.75	148.5	981	15.3	4	3799
1132N	16.10	148.4	983	15.3	4	3804
1140S	16.70	148.5	984	15.3	4	3816
Average	**16.40**	**148.4**	**983**	**15.3**	**4**	**3806**
*3330**	*17.50*	*160.0*	*1147*	*19.2*	*4*	*4505*

* *extracted from approach data for deceleration run from 100% ahead*
** *based on 2680hp (2MW) hotel load*

Table 6. USCGC HEALY (WAGB 20) standardization trials results, propulsion summary, 16,412 LT, 25-26 August 1999, US customary units.

Run Number	Ship Speed (knots)	Shaft Speed Stbd (rpm)	Shaft Speed Port (rpm)	Shaft Speed Average (rpm)	Shaft Torque Stbd (lbf-ft/1000)	Shaft Torque Port (lbf-ft/1000)	Shaft Torque Total (lbf-ft/1000)	Shaft Power Stbd (hp/1000)	Shaft Power Port (hp/1000)	Shaft Power Total (hp/1000)	Propulsion Plant Generators (online)	Fuel Consumption Propulsion Only ** Total (gal/hr)
1000N	8.70	85.9	85.9	85.9	122	124	245	2.0	2.0	4.0	3	218
1010S	10.95	84.9	85.5	85.2	123	124	248	2.0	2.0	4.0	3	215
1020N	8.60	85.9	85.9	85.9	122	124	246	2.0	2.0	4.0	3	215
Average	**9.80**			**85.6**			**247**			**4.0**	**3**	**216**
1030S	13.70	110.2	110.9	110.5	199	199	399	4.2	4.2	8.4	3	410
1040N	11.40	110.8	110.7	110.7	199	200	398	4.2	4.2	8.4	3	410
1050S	13.70	110.4	111.0	110.7	199	200	399	4.2	4.2	8.4	3	410
Average	**12.55**			**110.7**			**399**			**8.4**	**3**	**410**
1060N	13.10	127.7	127.9	127.8	266	268	534	6.5	6.5	13.0	3	608
1070S	15.60	127.6	128.1	127.8	266	267	534	6.5	6.5	13.0	3	605
1080N	13.00	127.8	127.9	127.9	266	269	535	6.5	6.6	13.0	3	605
Average	**14.33**			**127.8**			**534**			**13.0**	**3**	**606**
1090S	16.55	137.7	137.3	137.5	312	307	620	8.2	8.0	16.2	4	812
1100N	14.00	137.8	136.9	137.4	312	309	621	8.2	8.1	16.2	4	810
1110S	16.65	137.7	137.3	137.5	312	307	620	8.2	8.0	16.2	4	808
Average	**15.30**			**137.4**			**620**			**16.2**	**4**	**810**
1130S	16.75	148.6	148.3	148.5	365	359	724	10.3	10.1	20.5	4	1004
1132N	16.10	148.6	148.2	148.4	366	360	725	10.4	10.2	20.5	4	1005
1140S	16.70	148.6	148.3	148.5	366	360	726	10.4	10.2	20.5	4	1008
Average	**16.40**			**148.4**			**725**			**20.5**	**4**	**1005**
*3330**	*17.50*	*159.4*	*160.5*	*160.0*	*426*	*420*	*846*	*12.9*	*12.8*	*25.8*	*4*	*1190*

* *extracted from approach data for deceleration run from 100% ahead*
** *based on 2680hp (2MW) hotel load*

Table 7. USCGC HEALY (WAGB 20) standardization trials results, propulsion summary, 18,152 tonnes, 25-26 August 1999, metric units.

Run Number	Ship Speed (knots)	Shaft Speed Stbd (rpm)	Shaft Speed Port (rpm)	Shaft Speed Average (rpm)	Shaft Torque Stbd (N-m/1000)	Shaft Torque Port (N-m/1000)	Shaft Torque Total (N-m/1000)	Shaft Power Stbd (MW)	Shaft Power Port (MW)	Shaft Power Total (MW)	Propulsion Plant Generators (online)	Fuel Consumption Propulsion Only ** Total (liters/hr)
1000N	8.70	85.9	85.9	85.9	165	168	333	1.5	1.5	3.0	3	825
1010S	10.95	84.9	85.5	85.2	167	168	336	1.5	1.5	3.0	3	816
1020N	8.60	85.9	85.9	85.9	166	167	333	1.5	1.5	3.0	3	812
Average	**9.80**			**85.6**			**334**			**3.0**	**3**	**817**
1030S	13.70	110.2	110.9	110.5	270	270	541	3.1	3.1	6.2	3	1554
1040N	11.40	110.8	110.7	110.7	269	271	540	3.1	3.1	6.3	3	1552
1050S	13.70	110.4	111.0	110.7	270	271	541	3.1	3.2	6.3	3	1553
Average	**12.55**			**110.7**			**541**			**6.3**	**3**	**1553**
1060N	13.10	127.7	127.9	127.8	361	364	725	4.8	4.9	9.7	3	2302
1070S	15.60	127.6	128.1	127.8	361	362	723	4.8	4.9	9.7	3	2289
1080N	13.00	127.8	127.9	127.9	361	364	725	4.8	4.9	9.7	3	2291
Average	**14.33**			**127.8**			**724**			**9.7**	**3**	**2293**
1090S	16.55	137.7	137.3	137.5	423	417	840	6.1	6.0	12.1	4	3074
1100N	14.00	137.8	136.9	137.4	423	419	842	6.1	6.0	12.1	4	3065
1110S	16.65	137.7	137.3	137.5	423	417	840	6.1	6.0	12.1	4	3060
Average	**15.30**			**137.4**			**841**			**12.1**	**4**	**3066**
1130S	16.75	148.6	148.3	148.5	495	487	981	7.7	7.6	15.3	4	3799
1132N	16.10	148.6	148.2	148.4	496	488	983	7.7	7.6	15.3	4	3804
1140S	16.70	148.6	148.3	148.5	496	488	984	7.7	7.6	15.3	4	3816
Average	**16.40**			**148.4**			**983**			**15.3**	**4**	**3806**
*3330**	*17.50*	*159.4*	*160.5*	*160.0*	*578*	*569*	*1147*	*9.6*	*9.6*	*19.2*	*4*	*4505*

* *extracted from approach data for deceleration run from 100% ahead*
** *based on 2680hp (2MW) hotel load*

Table 8. USCGC HEALY (WAGB 20) standardization trials results, fuel summary, 16,412 LT, 25-26 August 1999, US customary units.

Run Number	Ship Speed (knots)	Shaft Speed Average (rpm)	Shaft Torque Total (lbf-ft/1000)	Shaft Power Total (hp/1000)	Fuel Rates Generator 1 Supply (gal/hr)	Fuel Rates Generator 1 Return (gal/hr)	Fuel Rates Generator 2 Supply (gal/hr)	Fuel Rates Generator 2 Return (gal/hr)	Fuel Rates Generator 3 Supply (gal/hr)	Fuel Rates Generator 3 Return (gal/hr)	Fuel Rates Generator 4 Supply (gal/hr)	Fuel Rates Generator 4 Return (gal/hr)	Fuel Consumption Generator 1 (gal/hr)	Fuel Consumption Generator 2 (gal/hr)	Fuel Consumption Generator 3 (gal/hr)	Fuel Consumption Generator 4 (gal/hr)	Fuel Consumption Total (gal/hr)	Fuel Consumption Propulsion Only ** Total (gal/hr)
1000N	8.70	85.9	245	4.0	1027	908	***	***	988	868	981	857	119	***	120	124	364	218
1010S	10.95	85.2	248	4.0	1025	908	***	***	986	868	980	857	118	***	119	122	359	215
1020N	8.60	85.9	246	4.0	1026	908	***	***	987	869	981	859	118	***	118	122	357	215
Average	**9.80**	**85.6**	**247**	**4.0**	**1026**	**908**	***	***	**987**	**868**	**980**	**858**	**118**	***	**119**	**123**	**360**	**216**
1030S	13.70	110.5	399	8.4	1052	873	***	***	1008	829	1005	821	179	***	178	184	542	410
1040N	11.40	110.7	398	8.4	1053	874	***	***	1008	829	1005	822	179	***	178	184	541	410
1050S	13.70	110.7	399	8.4	1053	874	***	***	1007	829	1005	821	179	***	178	184	541	410
Average	**12.55**	**110.7**	**399**	**8.4**	**1053**	**874**	***	***	**1007**	**829**	**1005**	**821**	**179**	***	**178**	**184**	**541**	**410**
1060N	13.10	127.8	534	13.0	1091	847	***	***	1035	792	1043	796	243	***	242	248	733	608
1070S	15.60	127.8	534	13.0	1091	849	***	***	1033	792	1042	797	242	***	241	246	729	605
1080N	13.00	127.9	535	13.0	1091	849	***	***	1033	792	1044	797	242	***	241	247	730	605
Average	**14.35**	**127.8**	**534**	**13.0**	**1091**	**848**	***	***	**1034**	**792**	**1043**	**796**	**243**	***	**242**	**246**	**731**	**606**
1090S	16.55	137.5	620	16.2	1090	868	1079	804	1035	812	1041	815	222	275	222	226	946	812
1100N	14.00	137.4	621	16.2	1090	869	1079	806	1034	812	1041	816	222	273	222	226	943	810
1110S	16.65	137.5	620	16.2	1089	868	1079	806	1034	812	1041	816	221	273	222	225	942	808
Average	**15.30**	**137.4**	**620**	**16.2**	**1090**	**868**	**1079**	**805**	**1034**	**812**	**1041**	**815**	**222**	**274**	**222**	**226**	**944**	**810**
1130S	16.75	148.5	724	20.5	1091	822	1088	768	1040	769	1053	777	269	320	270	276	1135	1004
1132N	16.10	148.4	725	20.5	1091	822	1089	769	1039	769	1055	778	269	320	270	277	1136	1005
1140S	16.70	148.5	726	20.5	1092	821	1089	769	1040	768	1055	777	270	320	272	278	1140	1008
Average	**16.40**	**148.4**	**725**	**20.5**	**1091**	**822**	**1089**	**769**	**1040**	**769**	**1054**	**777**	**269**	**320**	**271**	**277**	**1137**	**1005**
3330*	***17.50***	***160.0***	***846***	***25.8***	***1062***	***744***	***1110***	***774***	***1080***	***756***	***1158***	***822***	***318***	***336***	***324***	***336***	***1314***	***1190***

** extracted from approach data for deceleration run from 100% ahead*
*** based on 2680hp (2MW) Hotel load*
**** denotes generator offline*

Average Fuel Temperatures
Supply = 115 deg F
Return = 135 deg F

Table 9. USCGC HEALY (WAGB 20) standardization trials results, fuel summary, 18,152 tonnes, 25-26 August 1999, metric units.

Run Number	Ship Speed (knots)	Shaft Speed Average (rpm)	Shaft Torque Total (N-m/1000)	Shaft Power Total (MW)	Fuel Rates Generator 1 Supply (liters/hr)	Fuel Rates Generator 1 Return (liters/hr)	Fuel Rates Generator 2 Supply (liters/hr)	Fuel Rates Generator 2 Return (liters/hr)	Fuel Rates Generator 3 Supply (liters/hr)	Fuel Rates Generator 3 Return (liters/hr)	Fuel Rates Generator 4 Supply (liters/hr)	Fuel Rates Generator 4 Return (liters/hr)	Fuel Consumption Generator 1 (liters/hr)	Fuel Consumption Generator 2 (liters/hr)	Fuel Consumption Generator 3 (liters/hr)	Fuel Consumption Generator 4 (liters/hr)	Fuel Consumption Total (liters/hr)	Fuel Consumption Propulsion Only ** Total (liters/hr)
1000N	8.70	85.9	333	3.0	3888	3437	***	***	3740	3285	3713	3243	452	***	456	470	1377	825
1010S	10.95	85.2	336	3.0	3881	3436	***	***	3734	3284	3709	3246	446	***	450	464	1359	816
1020N	8.60	85.9	333	3.0	3884	3439	***	***	3735	3290	3712	3250	446	***	446	462	1353	812
Average	**9.80**	**85.6**	**334**	**3.0**	**3884**	**3437**	***	***	**3736**	**3286**	**3711**	**3246**	**447**	***	**450**	**465**	**1362**	**817**
1030S	13.70	110.5	541	6.3	3984	3305	***	***	3814	3138	3804	3108	679	***	675	696	2050	1554
1040N	11.40	110.7	540	6.3	3986	3309	***	***	3814	3139	3806	3110	677	***	675	696	2048	1552
1050S	13.70	110.7	541	6.3	3984	3308	***	***	3813	3138	3806	3109	676	***	675	697	2048	1553
Average	**12.55**	**110.7**	**541**	**6.3**	**3985**	**3308**	***	***	**3814**	**3139**	**3805**	**3109**	**677**	***	**675**	**696**	**2048**	**1553**
1060N	13.10	127.8	725	9.7	4128	3207	***	***	3917	2999	3949	3012	921	***	918	937	2776	2302
1070S	15.60	127.8	723	9.7	4131	3213	***	***	3912	2999	3945	3015	918	***	913	930	2761	2289
1080N	13.00	127.9	725	9.7	4130	3214	***	***	3911	2997	3950	3017	916	***	914	933	2763	2291
Average	**14.35**	**127.8**	**724**	**9.7**	**4130**	**3212**	***	***	**3913**	**2998**	**3947**	**3015**	**918**	***	**914**	**933**	**2765**	**2293**
1090S	16.55	137.5	840	12.1	4127	3286	4085	3044	3917	3075	3941	3084	841	1042	842	856	3581	3074
1100N	14.00	137.4	842	12.1	4128	3288	4085	3051	3915	3074	3942	3087	840	1035	841	854	3571	3065
1110S	16.65	137.5	840	12.1	4123	3285	4085	3051	3914	3073	3941	3089	838	1034	841	852	3565	3060
Average	**15.30**	**137.4**	**841**	**12.1**	**4126**	**3287**	**4085**	**3049**	**3915**	**3074**	**3941**	**3087**	**840**	**1036**	**841**	**854**	**3572**	**3066**
1130S	16.75	148.5	981	15.3	4129	3111	4118	2909	3935	2911	3985	2940	1018	1209	1024	1045	4297	3799
1132N	16.10	148.4	983	15.3	4131	3112	4121	2910	3934	2912	3992	2943	1019	1211	1023	1048	4301	3804
1140S	16.70	148.5	984	15.3	4132	3109	4123	2912	3936	2908	3994	2942	1023	1211	1028	1052	4315	3816
Average	**16.40**	**148.4**	**983**	**15.3**	**4131**	**3111**	**4121**	**2910**	**3935**	**2910**	**3991**	**2942**	**1020**	**1211**	**1024**	**1048**	**4304**	**3806**
3330	*17.50*	*160.0*	*846*	*25.8*	*4020*	*2816*	*4202*	*2930*	*4088*	*2862*	*4383*	*3112*	*1204*	*1272*	*1226*	*1272*	*4974*	*4505*

** extracted from approach data for deceleration run from 100% ahead*
*** based on 2680hp (2MW) Hotel load*
**** denotes generator offline*

Average Fuel Temperatures
Supply = 115 deg F
Return = 135 deg F

Table 10. USCGC HEALY (WAGB 20) standardization trials results, ship speed and shaft speed relationship, 16,412 LT (18,152 tonnes), 25-26 August 1999.

Ship Speed (knots)	Shaft Speed (rpm)
8.0	65
8.5	70
9.0	75
9.5	80
10.0	85
10.5	90
11.0	95
11.5	100
12.0	105
12.5	110
13.0	115
13.5	120
14.0	125
14.5	130
15.0	135
15.5	140
16.0	145
16.5	150
17.0	155
17.5	160

Table 11. USCGC HEALY (WAGB 20) standardization trials results, shaft power and fuel consumption relationship, 16,412 LT (18,152 tonnes), 25-26 August 1999.

Shaft Power Total		Fuel Consumption Propulsion System			
(hp)	(kW)	(gal/hr)	(liters/hr)	(gal/nm)	(l/nm)
4000	2984	215	814	22	83
5000	3730	255	965	24	92
6000	4476	305	1155	27	104
7000	5222	355	1344	30	114
8000	5968	400	1514	33	123
9000	6714	450	1704	35	133
10000	7460	500	1893	38	143
11000	8206	545	2063	40	151
12000	8952	590	2233	42	159
13000	9698	635	2404	44	167
14000	10444	687	2600	47	177
15000	11190	733	2775	49	185
16000	11936	779	2948	51	193
17000	12682	824	3120	53	201
18000	13428	869	3290	55	208
19000	14174	914	3458	57	216
20000	14920	958	3625	59	223
21000	15666	1001	3790	61	230
22000	16412	1045	3954	63	237
23000	17158	1087	4116	64	244
24000	17904	1130	4277	66	250
25000	18650	1172	4436	68	256
26000	19396	1214	4593	69	262

Nominal values based on curve fits from Figure 6.

TACTICAL TRIALS

A series of tactical turns were conducted on HEALY to determine the ship's turning characteristics for various combinations of ship speeds and rudder angles. Three different right rudder angles were tested for nominal approach speeds of 8, 12.5, and 16.5 knots. In addition to the nine turns using right rudder, a port turn was accomplished at an approach speed of 13 knots. This check turn was accomplished to verify that the ship's turning characteristics were the same whether using right or left rudder. As shown in Table 3, weather conditions were excellent throughout the trials and the turning characteristics determined are considered to accurately represent the capabilities of HEALY.

TACTICAL TRIALS PROCEDURES

Each turn was commenced only after steady approach conditions had been established and maintained during the approach or COMEX portion of the run.. The commands and actions used to conduct the trials are defined as follows:

STANDBY: Steady approach conditions have been established. One minute to COMEX.

COMEX: Commence data acquisition. Maintain steady conditions. One minute to EXECUTE.

EXECUTE: The rudder is positioned smartly to the scheduled angle. The rudder and throttle are held steady until the completion of the turn (540 degrees change of heading).

FINEX: Terminate the run and data acquisition.

The typical path of a tactical turn conducted in an environment with no wind or current is illustrated in Figure 7.

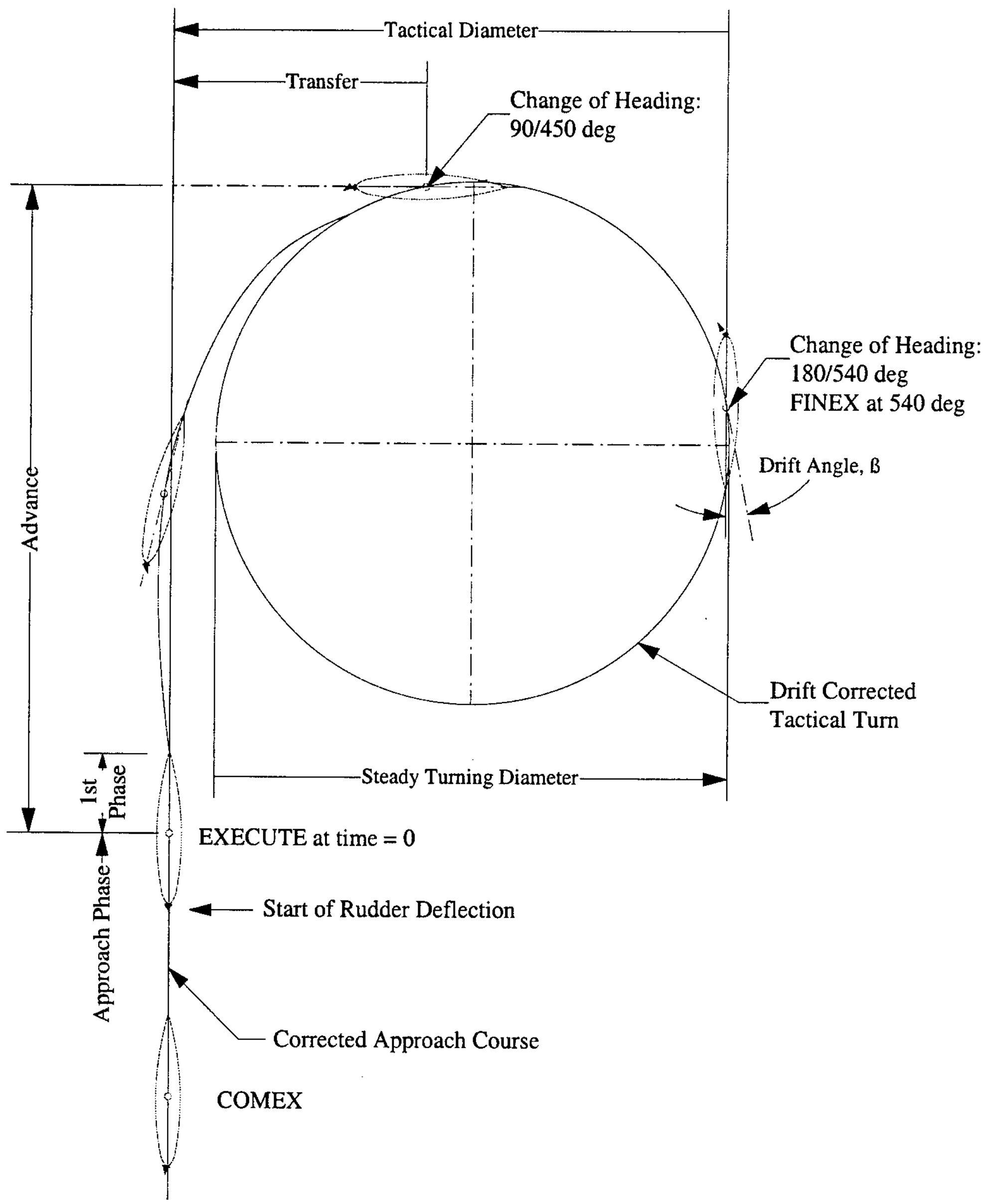

Fig. 7. Typical path of ship during a drift corrected tactical turn run.

Tactical data included in this report have been corrected for drift due to the effects of water current and wind, and thus represent the turning characteristics for HEALY operating in an environment of still wind and water. This is the only way in which standardized data can be developed. The uncorrected turning characteristics of HEALY will vary about the values presented in this report in response to the effects of water current, wind, and sea state that exist at the time a given tactical maneuver is conducted.

To correct the ship's path during the tactical turn, an average drift vector for each circle was determined by dividing the difference in position by the elapsed time for ship positions at which the heading differs by 360 degrees. This drift calculation was performed only after the ship had reached a steady turning rate (after 120 degrees of heading change). As an example, a drift vector may be determined from the difference in position and time for a ship at headings of 150 degrees and 510 degrees. These drift vectors are used to adjust each positional data point measured during the run and thus correct the data to represent the environment of still wind and water. (As described in a later section, drift vectors determined during the tactical turns are also used to correct acceleration and deceleration maneuvers for the effect of wind and current). An example of the difference between the uncorrected and the corrected path of a ship is shown in Figure 8.

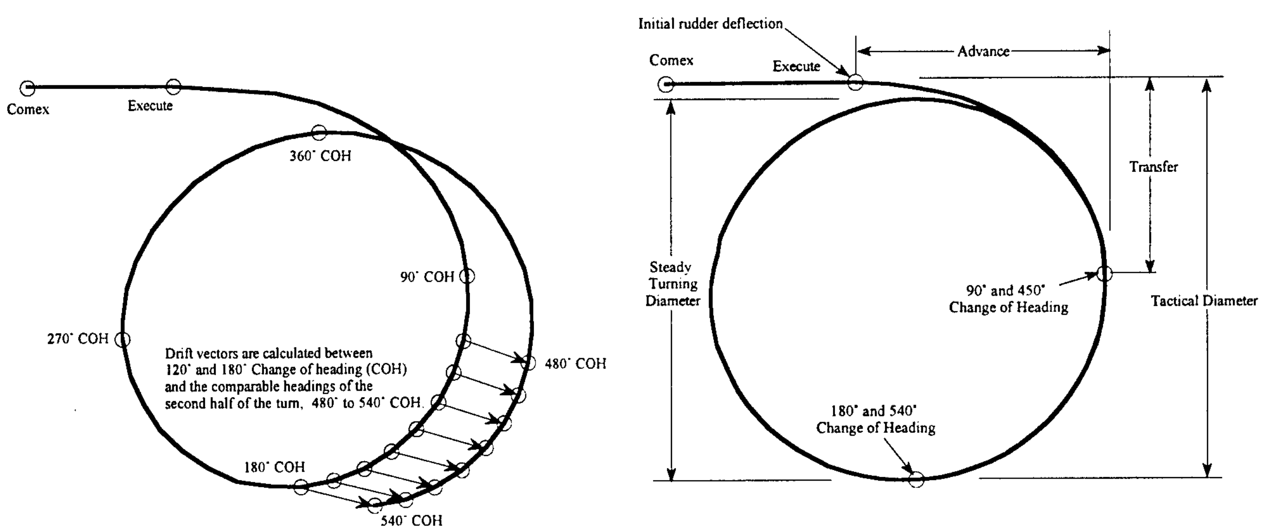

Fig. 8. Comparison of the paths for uncorrected and corrected conventional tactical turns.

TACTICAL TRIALS RESULTS

Advance, transfer, and tactical diameter as a function of steady approach speed are shown in Fig. 9. This figure indicates that the advance, transfer, and tactical diameter of HEALY are only slightly dependent on ship speed. When using a nominal rudder angle of 35 degrees, for example, advance varies by only 20 yards when ship approach speed is between 8 knots and 16.5 knots.

Figure 9 indicates that transfer and tactical diameter also only increase slightly as a function of speed when a rudder angle of 10 degrees is used. Based on the results of a port turn with a nominal 20 degrees rudder angle as shown in Figure 9, HEALY turns the same to the port as it does to the starboard. This is a desirable characteristic and is typical of ships with two propellers. Figure 9 also indicates that the tactical diameter of HEALY is approximately 3 ship lengths for all speeds tested when a rudder angle of 35 degrees is used.

Figure 10 and Table 12 indicate that the turning characteristics of HEALY change substantially as a function of rudder angle. Tactical diameter decreases from approximately 750 yards (685 meters) to approximately 375 yards (343 meters) as rudder angle is increased from 10 degrees to 35 degrees. The fact that the three curves shown in Fig. 9 represent three different speeds, and the curves essentially coincide for each parameter shown (advance, transfer, and tactical diameter) again indicates only slight dependence of ship turning characteristics on ship approach speed.

Figures 11 - 13 show the advance versus transfer characteristics for HEALY at approach speeds of 8, 12.5, and 16.5 knots respectively. These figures can be used to determine either the advance or the transfer of HEALY for each 10 degrees of heading change for heading changes between 0 degrees and 180 degrees. Again, these distances represent the turning characteristics of HEALY for the condition of zero wind and zero current. Figures 14 - 16 show the change of heading versus time characteristics for HEALY at approach speeds of 8, 12.5, and 16.5 knots respectively. Characteristics shown in these figures will be altered by environmental conditions that exist at the time a given maneuver is accomplished. Tables 12 through 15 provide the standardized turning characteristics of HEALY in tabular form.

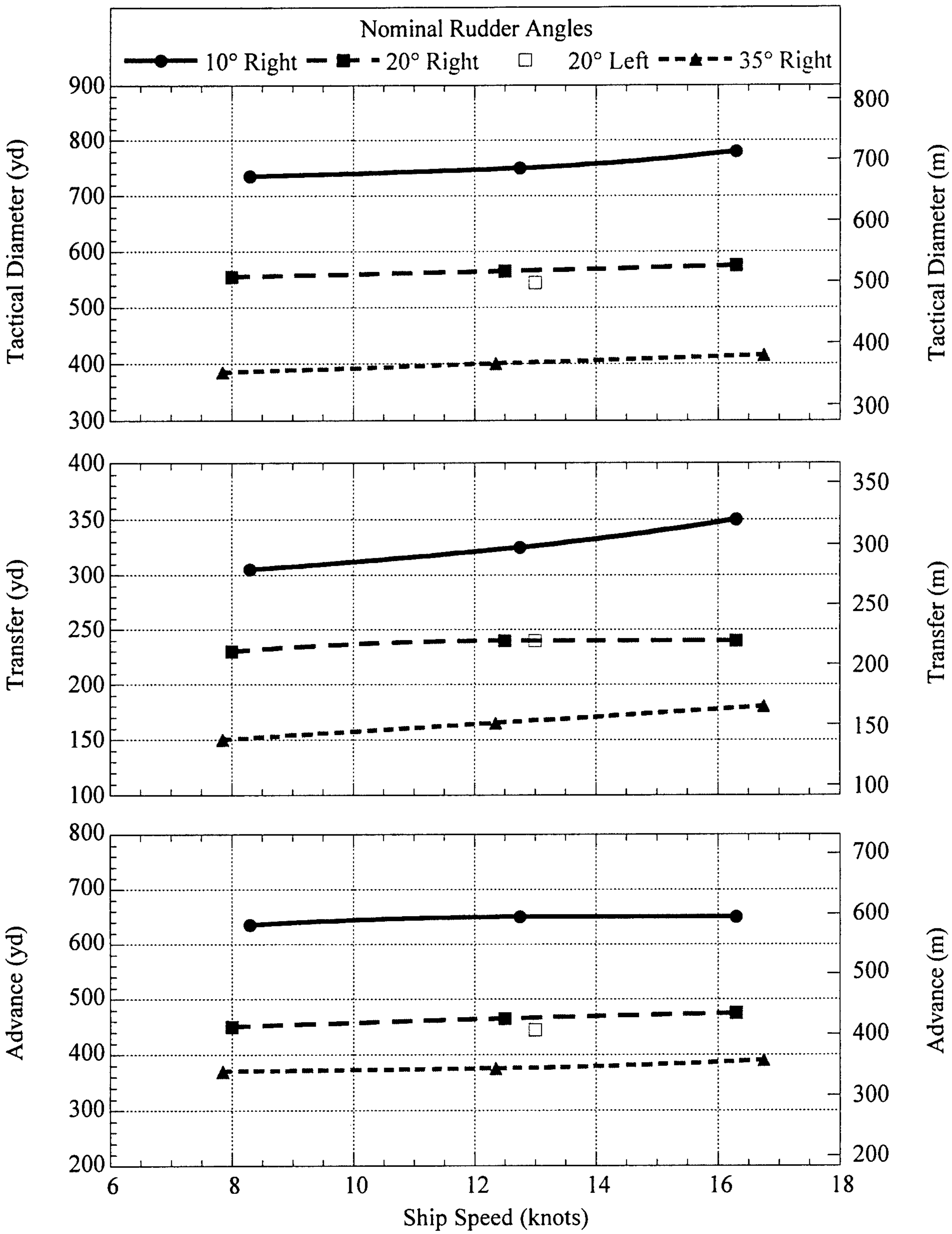

Fig. 9. USCGC HEALY (WAGB 20) tactical trials results, tactical dimensions versus approach ship speed.

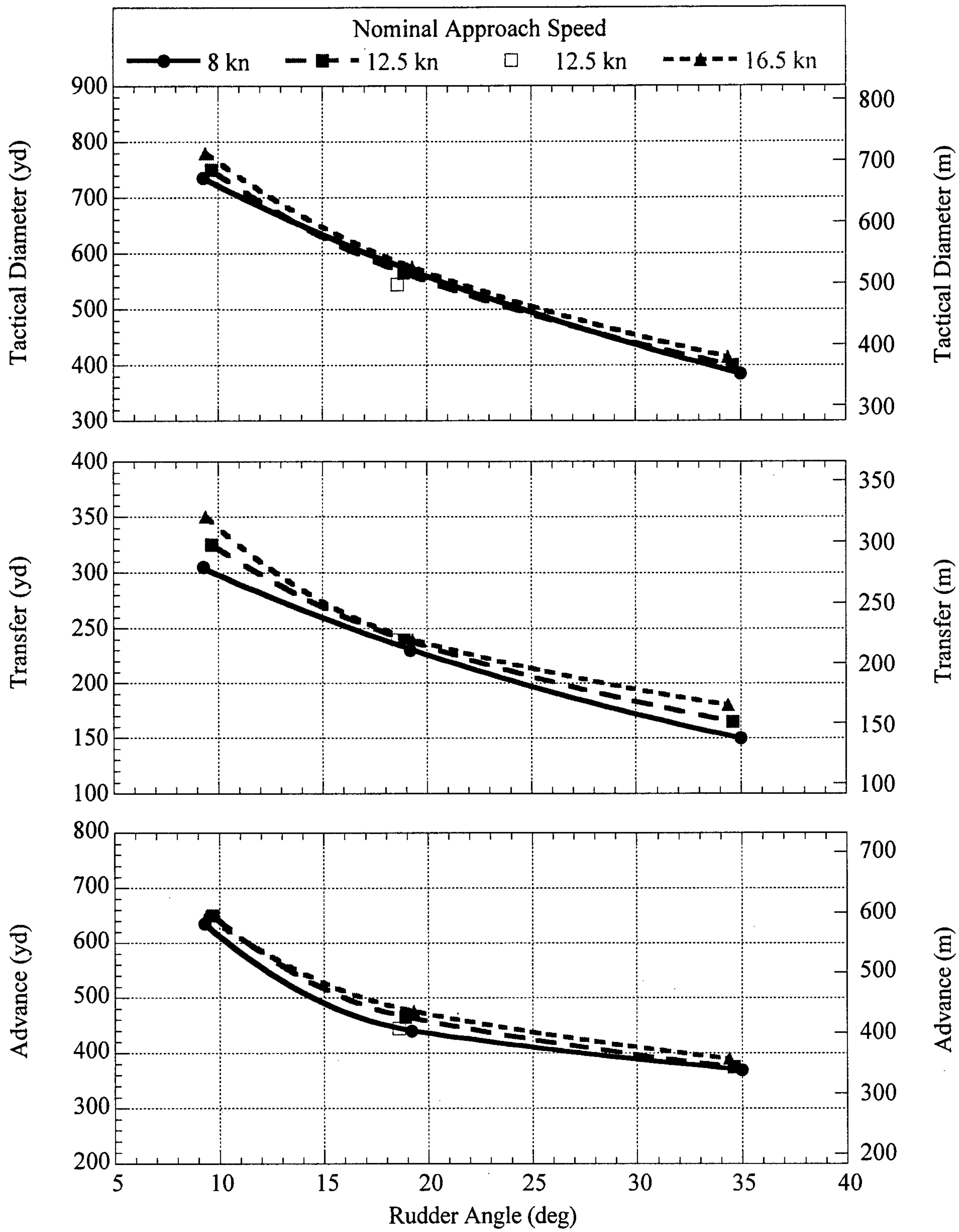

Fig. 10. USCGC HEALY (WAGB 20) tactical trials results, tactical dimensions versus rudder angle.

Change of Heading (deg)	9.3 deg Right Rudder Time to Change of Heading (s)	Advance (yd) | (m)	Transfer (yd) | (m)	19.2 deg Right Rudder Time to Change of Heading (s)	Advance (yd) | (m)	Transfer (yd) | (m)	35.0 deg Right Rudder Time to Change of Heading (s)	Advance (yd) | (m)	Transfer (yd) | (m)
0	0	0 | 0	0 | 0	0	0 | 0	0 | 0	0	0 | 0	0 | 0
10	52	237 | 217	-5 | -5	31	145 | 132	5 | 5	29	127 | 116	-9 | -9
20	73	331 | 303	7 | 7	46	211 | 193	14 | 13	41	179 | 164	-2 | -2
30	90	401 | 367	27 | 25	58	263 | 240	29 | 27	51	222 | 203	7 | 7
40	106	460 | 421	54 | 49	70	308 | 282	48 | 44	61	258 | 235	21 | 19
50	121	515 | 471	93 | 85	83	352 | 322	78 | 72	71	290 | 265	38 | 35
60	136	557 | 510	134 | 122	94	386 | 353	110 | 100	81	315 | 288	66 | 61
70	151	595 | 544	190 | 174	106	415 | 379	150 | 137	91	338 | 309	92 | 84
80	166	624 | 570	243 | 222	118	434 | 396	173 | 158	101	355 | 325	122 | 111
90	183	636 | 581	306 | 280	131	452 | 413	232 | 212	111	371 | 339	152 | 139
100	200	643 | 588	373 | 341	143	456 | 417	275 | 251	122	377 | 345	185 | 169
110	216	638 | 584	433 | 396	156	460 | 420	324 | 296	133	379 | 347	218 | 199
120	233	622 | 569	497 | 454	170	451 | 412	372 | 340	144	375 | 343	248 | 227
130	249	596 | 545	554 | 507	184	428 | 391	415 | 379	155	364 | 333	280 | 256
140	266	562 | 514	608 | 556	197	405 | 371	454 | 415	167	347 | 317	308 | 282
150	282	514 | 470	654 | 598	212	372 | 340	486 | 444	179	328 | 300	334 | 305
160	299	460 | 421	690 | 631	226	339 | 310	519 | 474	191	307 | 281	357 | 327
170	316	402 | 368	716 | 654	241	290 | 266	538 | 492	203	276 | 253	374 | 342
180	332	340 | 311	735 | 672	255	250 | 228	554 | 507	215	245 | 224	386 | 353

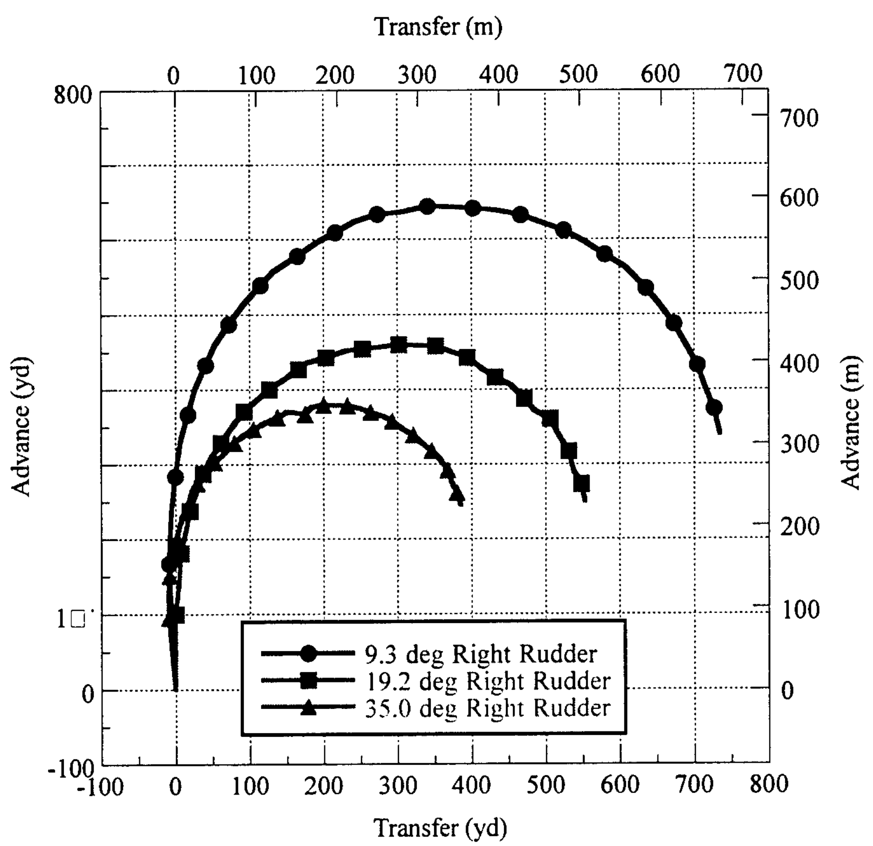

Fig. 11. USCGC HEALY (WAGB 20) tactical trials results, advance versus transfer for nominal 8 knots approach speed.

Change of Heading (deg)	9.7 deg Right Rudder: Time to Change of Heading (s)	Advance (yd)	Advance (m)	Transfer (yd)	Transfer (m)	18.9 deg Right Rudder: Time to Change of Heading (s)	Advance (yd)	Advance (m)	Transfer (yd)	Transfer (m)	18.6 deg Left Rudder: Time to Change of Heading (s)	Advance (yd)	Advance (m)	Transfer (yd)	Transfer (m)	34.6 deg Right Rudder: Time to Change of Heading (s)	Advance (yd)	Advance (m)	Transfer (yd)	Transfer (m)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	32	148	135	14	13	22	156	143	5	4	22	153	140	8	7	18	130	119	2	2
20	46	215	196	27	25	32	226	207	10	9	31	214	195	15	14	26	181	165	9	9
30	59	265	242	45	42	41	281	257	26	24	39	267	244	35	32	32	222	203	21	20
40	71	310	283	67	61	48	325	297	49	45	47	313	286	60	55	39	262	239	37	34
50	83	351	321	100	91	56	367	336	76	70	55	355	325	93	85	45	291	266	59	54
60	95	384	351	134	122	64	400	366	112	102	62	386	353	119	109	51	320	292	84	77
70	107	410	375	176	161	73	431	394	153	140	70	411	376	157	143	58	341	312	113	103
80	119	427	391	198	181	80	451	413	195	178	77	429	393	198	181	65	361	330	146	134
90	132	442	404	259	236	89	467	427	239	218	85	443	405	241	221	72	374	342	180	164
100	144	438	401	302	276	97	473	433	287	262	93	447	409	286	262	78	383	350	209	191
110	157	444	406	351	321	106	473	432	333	304	101	445	407	334	305	85	385	352	244	223
120	171	433	395	399	365	115	463	423	377	345	110	433	396	372	340	93	381	348	276	253
130	185	407	372	441	403	124	444	406	420	384	119	415	379	417	381	100	373	341	308	281
140	198	382	349	478	437	133	418	383	463	423	127	387	354	451	413	108	357	327	334	306
150	212	346	316	508	465	142	391	357	496	454	136	355	325	488	446	116	337	308	359	328
160	227	311	285	539	492	151	352	321	524	479	146	317	290	516	471	124	312	285	380	348
170	242	262	239	556	508	160	308	282	549	502	155	279	255	538	492	133	283	259	397	363
180	256	220	201	569	520	170	260	238	563	515	164	231	211	547	501	140	254	233	394	360

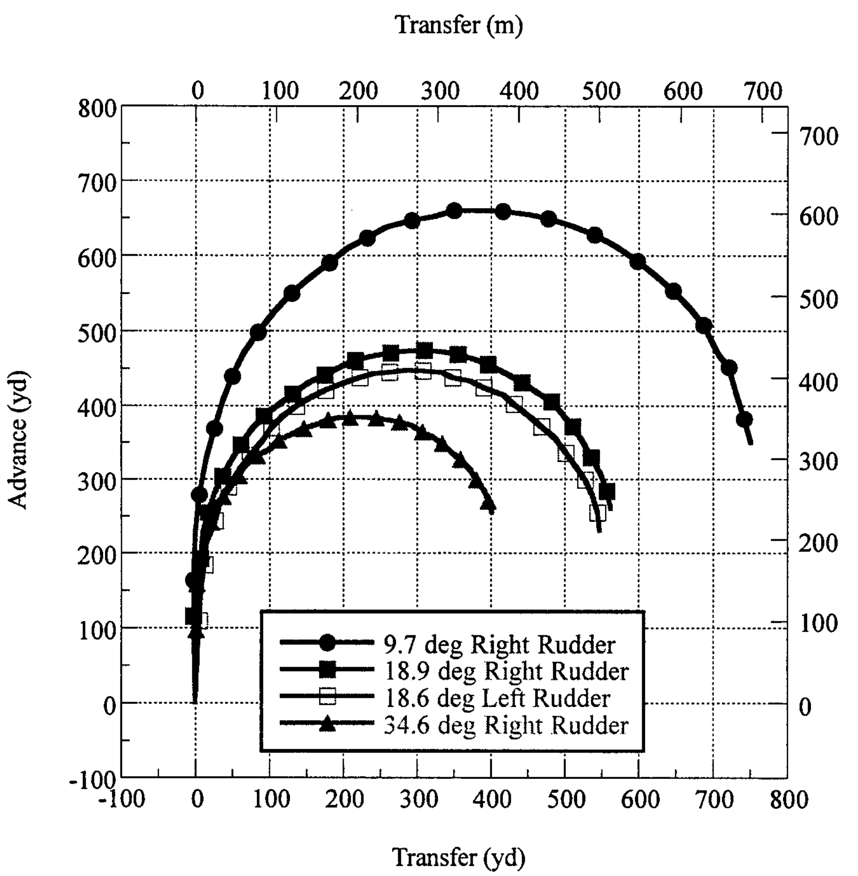

Fig. 12. USCGC HEALY (WAGB 20) tactical trials results, advance versus transfer for nominal 12.5 knots approach speed.

Change of Heading (deg)	9.4 deg Right Rudder: Time to Change of Heading (s)	Advance (yd)	Advance (m)	Transfer (yd)	Transfer (m)	19.3 deg Right Rudder: Time to Change of Heading (s)	Advance (yd)	Advance (m)	Transfer (yd)	Transfer (m)	34.4 deg Right Rudder: Time to Change of Heading (s)	Advance (yd)	Advance (m)	Transfer (yd)	Transfer (m)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	25	233	213	3	2	17	158	144	0	0	16	147	135	0	0
20	36	328	300	17	15	25	227	207	9	8	22	198	181	7	7
30	44	404	370	42	38	32	283	259	25	22	27	242	221	20	18
40	53	470	429	78	71	38	331	303	48	44	32	278	255	37	34
50	61	527	481	119	109	44	374	342	76	69	37	314	287	58	53
60	68	572	523	168	154	50	411	376	115	105	42	340	311	83	76
70	76	609	557	223	204	56	438	401	151	138	47	360	329	113	103
80	84	633	579	284	260	62	460	421	197	180	52	375	343	145	132
90	91	649	593	348	318	69	475	435	241	220	57	388	355	180	164
100	99	652	596	414	378	75	480	439	288	263	62	389	356	216	198
110	107	647	591	477	436	82	478	437	339	310	68	392	358	250	229
120	115	626	572	541	494	89	467	427	386	353	74	384	351	285	260
130	124	595	544	602	550	95	451	412	431	394	79	373	341	315	288
140	132	558	510	653	597	102	420	384	472	431	85	356	325	343	313
150	140	507	463	700	640	109	389	356	510	466	91	334	305	369	337
160	148	450	412	738	674	116	349	319	538	492	98	302	276	390	357
170	157	388	355	762	697	123	301	276	562	514	103	273	250	407	372
180	165	321	293	779	712	130	257	235	577	528	109	240	219	417	381

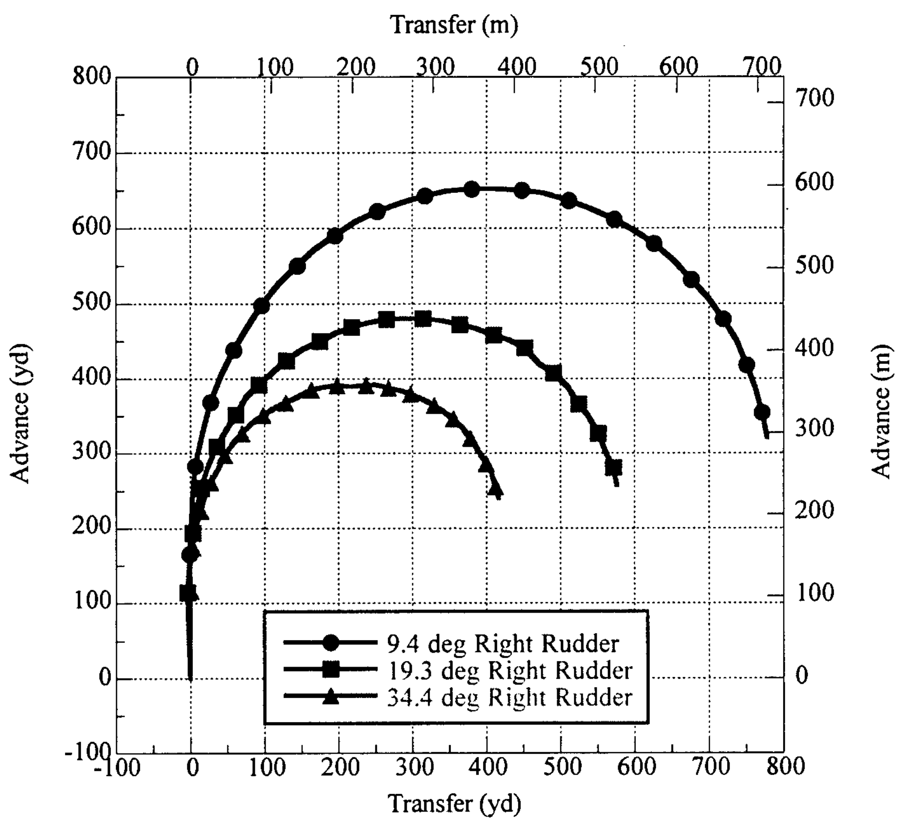

Fig. 13. USCGC HEALY (WAGB 20) tactical trials results, advance versus transfer for nominal 16.5 knots approach speed.

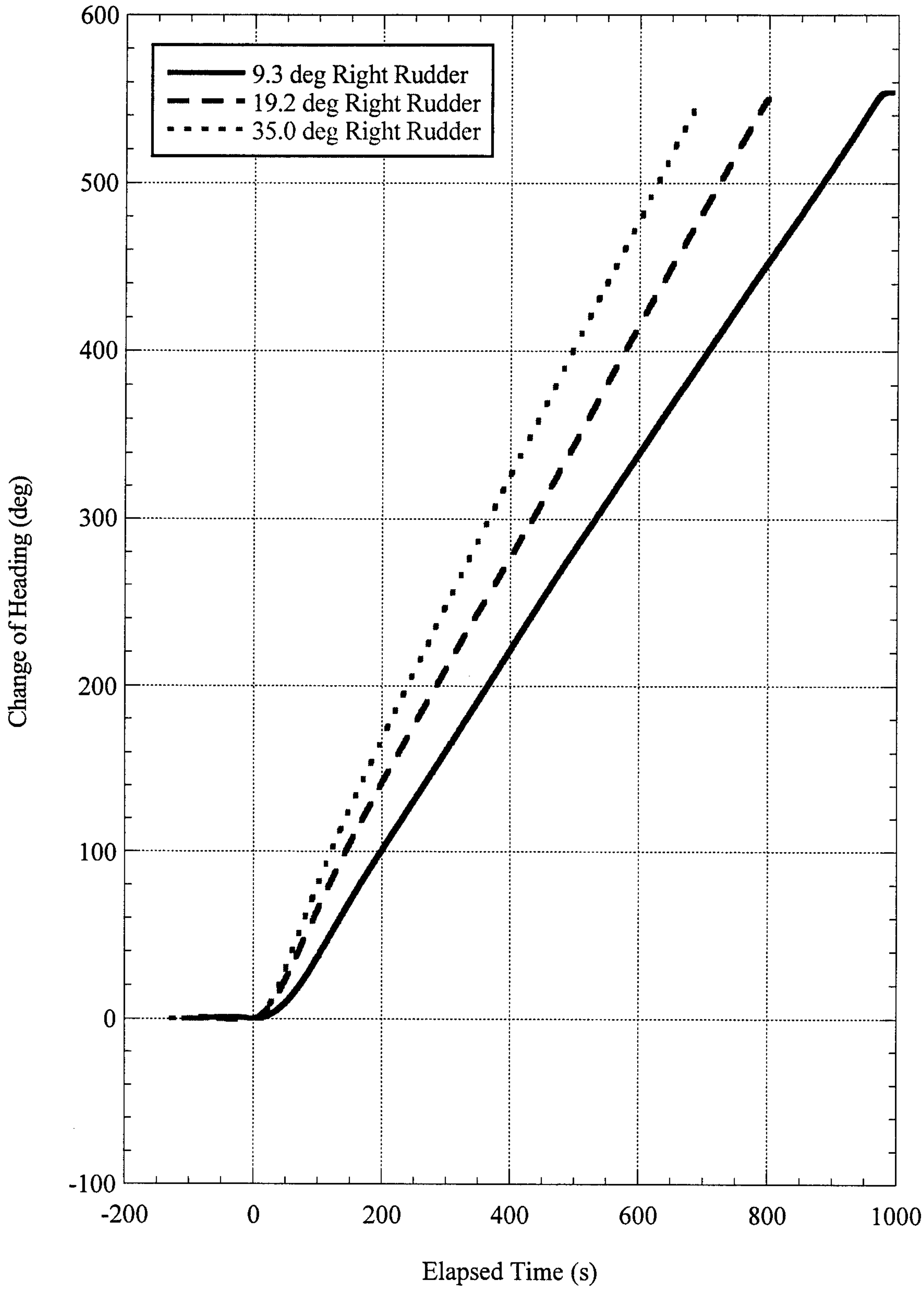

Fig. 14. USCGC HEALY (WAGB 20) tactical trials results, change of heading versus elapsed time for nominal 8 knots approach speed.

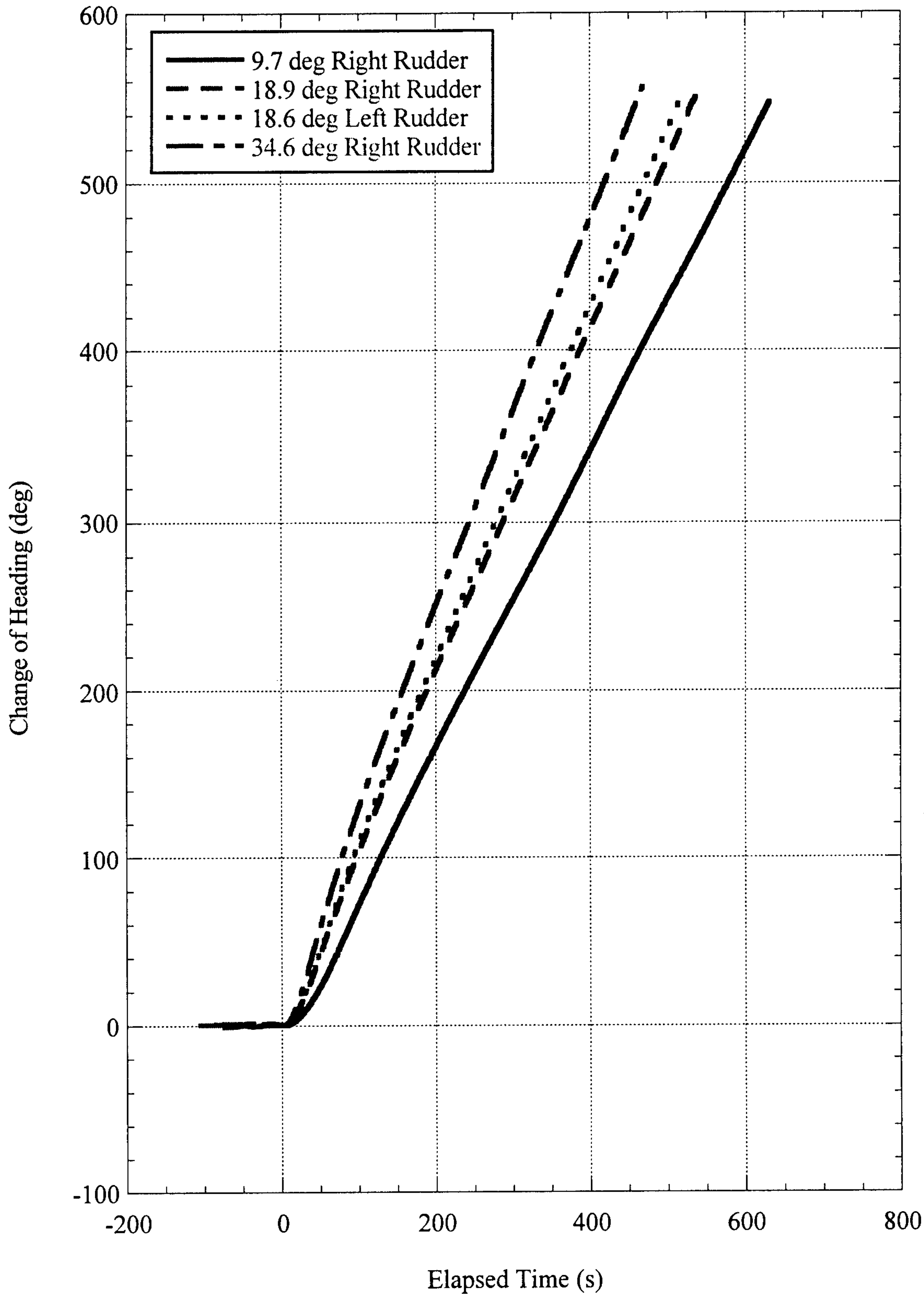

Fig. 15. USCGC HEALY (WAGB 20) tactical trials results, change of heading versus elapsed time for nominal 12.5 knots approach speed.

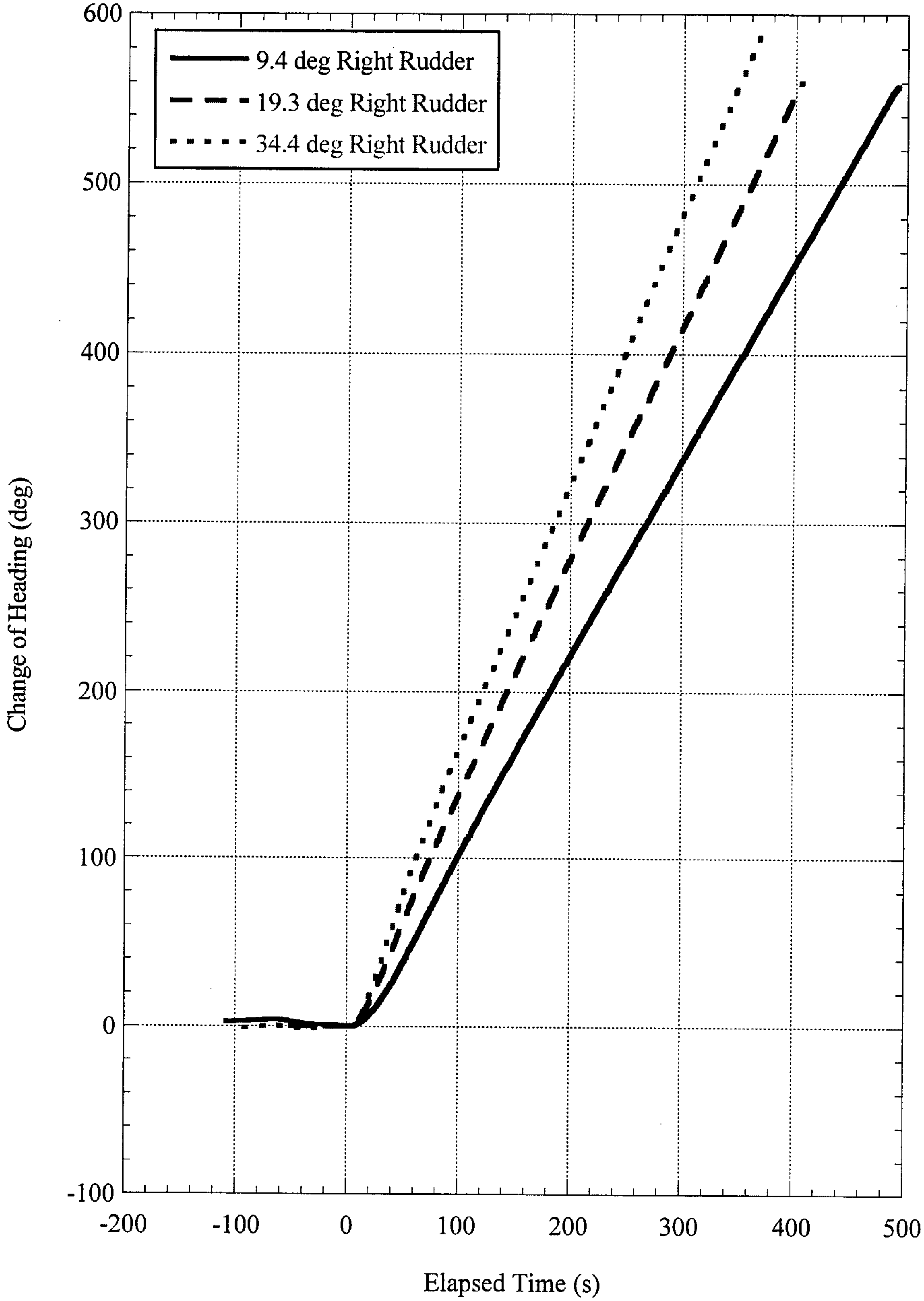

Fig. 16. USCGC HEALY (WAGB 20) tactical trials results, change of heading versus elapsed time for nominal 16.5 knots approach speed.

Table 12. USCGC HEALY (WAGB 20) tactical trials results.

Run Number	Approach Speed (knots)	Steady Rudder Angle (deg)	Advance (yd)	Advance (m)	Transfer (yd)	Transfer (m)	Tactical Diameter (yd)	Tactical Diameter (m)	Steady Turning Diameter (yd)	Steady Turning Diameter (m)	Steady Speed in Turn (knots)	Percent Speed Loss in Turn (%)	Time to 90 deg Chg of Hdg (s)	Time to 180 deg Chg of Hdg (s)	Time to 270 deg Chg of Hdg (s)	Time to 360 deg Chg of Hdg (s)	Steady Yaw Rate (deg/s)	Maximum Roll Angle (deg)	Steady Roll Angle (deg)
2000	8.30	9.3 R	635	581	305	279	735	672	735	672	6.8	18.4	183	332	481	636	1.7	0.7 S	0.4 S
2010	8.00	19.2 R	450	411	230	210	555	507	560	512	5.9	26.4	131	255	389	521	1.5	0.8 S	0.4 S
2030	7.85	35.0 R	370	338	150	137	385	352	380	347	4.6	41.1	111	215	328	445	1.3	1.0 S	0.3 S
2040	12.75	9.7 R	650	594	325	297	750	686	775	709	10.6	16.6	119	215	319	421	1.1	1.9 S	1.3 S
2050	12.50	18.9 R	465	425	240	219	565	517	555	507	8.8	29.9	89	170	258	348	1.0	2.5 S	1.4 S
2055	13.00	18.6 L	445	407	240	219	545	498	535	489	8.6	33.8	85	164	249	337	1.0	3.2 P	2.1 P
2060	12.35	34.6 R	375	343	165	150	400	366	390	357	7.0	43.6	72	140	217	296	0.9	3.1 S	1.2 S
2070	16.30	9.4 R	650	594	350	320	780	713	790	722	14.3	12.3	91	165	242	320	0.9	3.7 S	2.8 S
2080	16.30	19.3 R	475	434	240	219	575	526	580	530	12.4	24.0	69	130	194	260	0.7	4.4 S	2.9 S
2090	16.75	34.4 R	390	357	180	165	415	379	405	370	9.9	40.9	57	109	167	224	0.6	5.2 S	2.6 S

Table 13. USCGC HEALY (WAGB 20) tactical trials results, advance versus transfer for nominal 8 knots approach speed.

	9.3 deg Right Rudder			19.2 deg Right Rudder			35.0 deg Right Rudder		
Change of Heading (deg)	Time to Change of Heading (s)	Advance (yd) | (m)	Transfer (yd) | (m)	Time to Change of Heading (s)	Advance (yd) | (m)	Transfer (yd) | (m)	Time to Change of Heading (s)	Advance (yd) | (m)	Transfer (yd) | (m)
0	0	0 | 0	0 | 0	0	0 | 0	0 | 0	0	0 | 0	0 | 0
5	38	167 | 153	-8 | -8	21	100 | 91	0 | 0	21	95 | 87	-9 | -8
10	52	237 | 217	-5 | -5	31	145 | 132	5 | 5	29	127 | 116	-9 | -9
15	63	284 | 260	0 | 0	39	181 | 166	8 | 7	35	151 | 138	-8 | -7
20	73	331 | 303	7 | 7	46	211 | 193	14 | 13	41	179 | 164	-2 | -2
25	82	367 | 336	17 | 15	52	238 | 218	20 | 18	46	200 | 183	2 | 2
30	90	401 | 367	27 | 25	58	263 | 240	29 | 27	51	222 | 203	7 | 7
35	98	433 | 396	42 | 38	65	288 | 263	37 | 34	56	238 | 218	16 | 14
40	106	460 | 421	54 | 49	70	308 | 282	48 | 44	61	258 | 235	21 | 19
45	113	488 | 446	73 | 66	76	329 | 301	62 | 57	66	274 | 251	30 | 27
50	121	515 | 471	93 | 85	83	352 | 322	78 | 72	71	290 | 265	38 | 35
55	128	539 | 493	115 | 105	88	371 | 339	94 | 85	76	303 | 277	53 | 48
60	136	557 | 510	134 | 122	94	386 | 353	110 | 100	81	315 | 288	66 | 61
65	144	578 | 529	165 | 151	100	400 | 366	127 | 116	86	329 | 300	80 | 73
70	151	595 | 544	190 | 174	106	415 | 379	150 | 137	91	338 | 309	92 | 84
75	159	609 | 557	216 | 198	112	427 | 390	166 | 152	95	347 | 318	105 | 96
80	166	624 | 570	243 | 222	118	434 | 396	173 | 158	101	355 | 325	122 | 111
85	175	633 | 579	274 | 250	124	443 | 405	204 | 187	106	363 | 332	138 | 126
90	183	636 | 581	306 | 280	131	452 | 413	232 | 212	111	371 | 339	152 | 139
95	191	644 | 589	342 | 312	137	454 | 415	253 | 231	116	367 | 336	175 | 160
100	200	643 | 588	373 | 341	143	456 | 417	275 | 251	122	377 | 345	185 | 169
105	207	641 | 586	403 | 368	150	460 | 420	302 | 276	127	379 | 347	200 | 183
110	216	638 | 584	433 | 396	156	460 | 420	324 | 296	133	379 | 347	218 | 199
115	224	633 | 579	467 | 427	164	458 | 419	352 | 322	138	379 | 347	233 | 213
120	233	622 | 569	497 | 454	170	451 | 412	372 | 340	144	375 | 343	248 | 227
125	241	612 | 560	526 | 481	177	443 | 405	395 | 361	149	370 | 338	264 | 241
130	249	596 | 545	554 | 507	184	428 | 391	415 | 379	155	364 | 333	280 | 256
135	258	580 | 530	580 | 531	190	416 | 381	433 | 396	161	358 | 327	293 | 268
140	266	562 | 514	608 | 556	197	405 | 371	454 | 415	167	347 | 317	308 | 282
145	275	535 | 489	636 | 582	204	388 | 355	471 | 431	173	339 | 310	322 | 294
150	282	514 | 470	654 | 598	212	372 | 340	486 | 444	179	328 | 300	334 | 305
155	291	487 | 446	674 | 616	219	361 | 330	506 | 463	185	318 | 291	347 | 317
160	299	460 | 421	690 | 631	226	339 | 310	519 | 474	191	307 | 281	357 | 327
165	307	432 | 395	705 | 644	234	317 | 290	531 | 486	197	292 | 267	368 | 336
170	316	402 | 368	716 | 654	241	290 | 266	538 | 492	203	276 | 253	374 | 342
175	324	375 | 343	727 | 664	248	273 | 250	549 | 502	209	262 | 239	381 | 348
180	332	340 | 311	735 | 672	255	250 | 228	554 | 507	215	245 | 224	386 | 353

Table 14. USCGC HEALY (WAGB 20) tactical trials results, advance versus transfer for nominal 12.5 knots approach speed.

<table>
<tr><th></th><th colspan="3">9.7 deg Right Rudder</th><th colspan="3">18.9 deg Right Rudder</th><th colspan="3">18.6 deg Left Rudder</th><th colspan="3">34.6 deg Right Rudder</th></tr>
<tr><th>Change of Heading (deg)</th><th>Time to Change of Heading (s)</th><th>Advance (yd) | (m)</th><th>Transfer (yd) | (m)</th><th>Time to Change of Heading (s)</th><th>Advance (yd) | (m)</th><th>Transfer (yd) | (m)</th><th>Time to Change of Heading (s)</th><th>Advance (yd) | (m)</th><th>Transfer (yd) | (m)</th><th>Time to Change of Heading (s)</th><th>Advance (yd) | (m)</th><th>Transfer (yd) | (m)</th></tr>
<tr><td>0</td><td>0</td><td>0 | 0</td><td>0 | 0</td><td>0</td><td>0 | 0</td><td>0 | 0</td><td>0</td><td>0 | 0</td><td>0 | 0</td><td>0</td><td>0 | 0</td><td>0 | 0</td></tr>
<tr><td>5</td><td>22</td><td>104 | 95</td><td>6 | 5</td><td>16</td><td>115 | 106</td><td>-2 | -2</td><td>16</td><td>109 | 100</td><td>5 | 5</td><td>14</td><td>98 | 89</td><td>0 | 0</td></tr>
<tr><td>10</td><td>32</td><td>148 | 135</td><td>14 | 13</td><td>22</td><td>156 | 143</td><td>5 | 4</td><td>22</td><td>153 | 140</td><td>8 | 7</td><td>18</td><td>130 | 119</td><td>2 | 2</td></tr>
<tr><td>15</td><td>39</td><td>185 | 169</td><td>19 | 18</td><td>28</td><td>192 | 176</td><td>8 | 7</td><td>26</td><td>184 | 168</td><td>13 | 11</td><td>22</td><td>159 | 145</td><td>3 | 3</td></tr>
<tr><td>20</td><td>46</td><td>215 | 196</td><td>27 | 25</td><td>32</td><td>226 | 207</td><td>10 | 9</td><td>31</td><td>214 | 195</td><td>15 | 14</td><td>26</td><td>181 | 165</td><td>9 | 9</td></tr>
<tr><td>25</td><td>53</td><td>241 | 220</td><td>34 | 31</td><td>37</td><td>254 | 233</td><td>17 | 15</td><td>35</td><td>243 | 222</td><td>27 | 25</td><td>29</td><td>202 | 185</td><td>15 | 14</td></tr>
<tr><td>30</td><td>59</td><td>265 | 242</td><td>45 | 42</td><td>41</td><td>281 | 257</td><td>26 | 24</td><td>39</td><td>267 | 244</td><td>35 | 32</td><td>32</td><td>222 | 203</td><td>21 | 20</td></tr>
<tr><td>35</td><td>65</td><td>290 | 265</td><td>55 | 50</td><td>45</td><td>304 | 278</td><td>37 | 34</td><td>43</td><td>289 | 264</td><td>45 | 41</td><td>35</td><td>241 | 220</td><td>23 | 21</td></tr>
<tr><td>40</td><td>71</td><td>310 | 283</td><td>67 | 61</td><td>48</td><td>325 | 297</td><td>49 | 45</td><td>47</td><td>313 | 286</td><td>60 | 55</td><td>39</td><td>262 | 239</td><td>37 | 34</td></tr>
<tr><td>45</td><td>77</td><td>329 | 301</td><td>82 | 75</td><td>52</td><td>347 | 317</td><td>62 | 57</td><td>50</td><td>332 | 303</td><td>75 | 68</td><td>42</td><td>276 | 252</td><td>51 | 46</td></tr>
<tr><td>50</td><td>83</td><td>351 | 321</td><td>100 | 91</td><td>56</td><td>367 | 336</td><td>76 | 70</td><td>55</td><td>355 | 325</td><td>93 | 85</td><td>45</td><td>291 | 266</td><td>59 | 54</td></tr>
<tr><td>55</td><td>89</td><td>369 | 337</td><td>116 | 106</td><td>60</td><td>386 | 353</td><td>93 | 85</td><td>58</td><td>370 | 338</td><td>103 | 94</td><td>48</td><td>305 | 279</td><td>69 | 63</td></tr>
<tr><td>60</td><td>95</td><td>384 | 351</td><td>134 | 122</td><td>64</td><td>400 | 366</td><td>112 | 102</td><td>62</td><td>386 | 353</td><td>119 | 109</td><td>51</td><td>320 | 292</td><td>84 | 77</td></tr>
<tr><td>65</td><td>101</td><td>396 | 362</td><td>152 | 139</td><td>68</td><td>415 | 380</td><td>131 | 120</td><td>66</td><td>399 | 365</td><td>137 | 125</td><td>55</td><td>332 | 303</td><td>102 | 93</td></tr>
<tr><td>70</td><td>107</td><td>410 | 375</td><td>176 | 161</td><td>73</td><td>431 | 394</td><td>153 | 140</td><td>70</td><td>411 | 376</td><td>157 | 143</td><td>58</td><td>341 | 312</td><td>113 | 103</td></tr>
<tr><td>75</td><td>113</td><td>421 | 385</td><td>192 | 175</td><td>77</td><td>441 | 403</td><td>175 | 160</td><td>73</td><td>421 | 385</td><td>176 | 161</td><td>61</td><td>353 | 322</td><td>130 | 119</td></tr>
<tr><td>80</td><td>119</td><td>427 | 391</td><td>198 | 181</td><td>80</td><td>451 | 413</td><td>195 | 178</td><td>77</td><td>429 | 393</td><td>198 | 181</td><td>65</td><td>361 | 330</td><td>146 | 134</td></tr>
<tr><td>85</td><td>125</td><td>434 | 397</td><td>231 | 211</td><td>85</td><td>461 | 421</td><td>216 | 198</td><td>81</td><td>438 | 400</td><td>222 | 203</td><td>68</td><td>369 | 337</td><td>164 | 150</td></tr>
<tr><td>90</td><td>132</td><td>442 | 404</td><td>259 | 236</td><td>89</td><td>467 | 427</td><td>239 | 218</td><td>85</td><td>443 | 405</td><td>241 | 221</td><td>72</td><td>374 | 342</td><td>180 | 164</td></tr>
<tr><td>95</td><td>138</td><td>443 | 405</td><td>281 | 257</td><td>93</td><td>471 | 430</td><td>264 | 241</td><td>89</td><td>445 | 407</td><td>262 | 240</td><td>75</td><td>380 | 348</td><td>193 | 176</td></tr>
<tr><td>100</td><td>144</td><td>438 | 401</td><td>302 | 276</td><td>97</td><td>473 | 433</td><td>287 | 262</td><td>93</td><td>447 | 409</td><td>286 | 262</td><td>78</td><td>383 | 350</td><td>209 | 191</td></tr>
<tr><td>105</td><td>151</td><td>439 | 402</td><td>329 | 301</td><td>102</td><td>474 | 433</td><td>310 | 284</td><td>97</td><td>446 | 408</td><td>308 | 282</td><td>82</td><td>384 | 351</td><td>227 | 207</td></tr>
<tr><td>110</td><td>157</td><td>444 | 406</td><td>351 | 321</td><td>106</td><td>473 | 432</td><td>333 | 304</td><td>101</td><td>445 | 407</td><td>334 | 305</td><td>85</td><td>385 | 352</td><td>244 | 223</td></tr>
<tr><td>115</td><td>165</td><td>440 | 402</td><td>380 | 347</td><td>110</td><td>469 | 428</td><td>356 | 325</td><td>105</td><td>438 | 401</td><td>348 | 318</td><td>89</td><td>383 | 350</td><td>260 | 238</td></tr>
<tr><td>120</td><td>171</td><td>433 | 395</td><td>399 | 365</td><td>115</td><td>463 | 423</td><td>377 | 345</td><td>110</td><td>433 | 396</td><td>372 | 340</td><td>93</td><td>381 | 348</td><td>276 | 253</td></tr>
<tr><td>125</td><td>178</td><td>423 | 386</td><td>421 | 385</td><td>119</td><td>455 | 416</td><td>397 | 363</td><td>114</td><td>425 | 388</td><td>391 | 357</td><td>97</td><td>378 | 345</td><td>292 | 267</td></tr>
<tr><td>130</td><td>185</td><td>407 | 372</td><td>441 | 403</td><td>124</td><td>444 | 406</td><td>420 | 384</td><td>119</td><td>415 | 379</td><td>417 | 381</td><td>100</td><td>373 | 341</td><td>308 | 281</td></tr>
<tr><td>135</td><td>191</td><td>394 | 360</td><td>457 | 418</td><td>128</td><td>431 | 394</td><td>442 | 404</td><td>123</td><td>402 | 367</td><td>431 | 394</td><td>104</td><td>365 | 334</td><td>322 | 294</td></tr>
<tr><td>140</td><td>198</td><td>382 | 349</td><td>478 | 437</td><td>133</td><td>418 | 383</td><td>463 | 423</td><td>127</td><td>387 | 354</td><td>451 | 413</td><td>108</td><td>357 | 327</td><td>334 | 306</td></tr>
<tr><td>145</td><td>205</td><td>363 | 332</td><td>494 | 452</td><td>137</td><td>406 | 371</td><td>482 | 441</td><td>132</td><td>372 | 340</td><td>469 | 429</td><td>112</td><td>349 | 319</td><td>347 | 317</td></tr>
<tr><td>150</td><td>212</td><td>346 | 316</td><td>508 | 465</td><td>142</td><td>391 | 357</td><td>496 | 454</td><td>136</td><td>355 | 325</td><td>488 | 446</td><td>116</td><td>337 | 308</td><td>359 | 328</td></tr>
<tr><td>155</td><td>220</td><td>334 | 305</td><td>528 | 483</td><td>146</td><td>372 | 340</td><td>511 | 468</td><td>141</td><td>336 | 307</td><td>502 | 459</td><td>120</td><td>327 | 299</td><td>373 | 341</td></tr>
<tr><td>160</td><td>227</td><td>311 | 285</td><td>539 | 492</td><td>151</td><td>352 | 321</td><td>524 | 479</td><td>146</td><td>317 | 290</td><td>516 | 471</td><td>124</td><td>312 | 285</td><td>380 | 348</td></tr>
<tr><td>165</td><td>234</td><td>289 | 264</td><td>550 | 503</td><td>156</td><td>330 | 301</td><td>536 | 490</td><td>150</td><td>299 | 274</td><td>528 | 483</td><td>128</td><td>299 | 274</td><td>392 | 359</td></tr>
<tr><td>170</td><td>242</td><td>262 | 239</td><td>556 | 508</td><td>160</td><td>308 | 282</td><td>549 | 502</td><td>155</td><td>279 | 255</td><td>538 | 492</td><td>133</td><td>283 | 259</td><td>397 | 363</td></tr>
<tr><td>175</td><td>249</td><td>244 | 223</td><td>565 | 517</td><td>165</td><td>284 | 260</td><td>558 | 510</td><td>159</td><td>255 | 233</td><td>545 | 498</td><td>136</td><td>271 | 247</td><td>402 | 368</td></tr>
<tr><td>180</td><td>256</td><td>220 | 201</td><td>569 | 520</td><td>170</td><td>260 | 238</td><td>563 | 515</td><td>164</td><td>231 | 211</td><td>547 | 501</td><td>140</td><td>254 | 233</td><td>394 | 360</td></tr>
</table>

Table 15. USCGC HEALY (WAGB 20) tactical trials results, advance versus transfer for nominal 16.5 knots approach speed.

Change of Heading (deg)	9.4 deg Right Rudder: Time to Change of Heading (s)	Advance (yd) | (m)	Transfer (yd) | (m)	19.3 deg Right Rudder: Time to Change of Heading (s)	Advance (yd) | (m)	Transfer (yd) | (m)	34.4 deg Right Rudder: Time to Change of Heading (s)	Advance (yd) | (m)	Transfer (yd) | (m)
0	0	0 | 0	0 | 0	0	0 | 0	0 | 0	0	0 | 0	0 | 0
5	18	165 | 151	-1 | -1	13	115 | 105	-3 | -3	12	116 | 106	1 | 1
10	25	233 | 213	3 | 2	17	158 | 144	0 | 0	16	147 | 135	0 | 0
15	30	284 | 259	8 | 7	21	193 | 177	4 | 4	19	175 | 160	3 | 3
20	36	328 | 300	17 | 15	25	227 | 207	9 | 8	22	198 | 181	7 | 7
25	40	369 | 337	28 | 25	28	254 | 232	16 | 14	25	223 | 204	14 | 13
30	44	404 | 370	42 | 38	32	283 | 259	25 | 22	27	242 | 221	20 | 18
35	49	438 | 400	59 | 54	35	309 | 283	36 | 33	29	261 | 239	28 | 26
40	53	470 | 429	78 | 71	38	331 | 303	48 | 44	32	278 | 255	37 | 34
45	56	498 | 455	96 | 88	41	352 | 322	62 | 56	34	298 | 272	46 | 42
50	61	527 | 481	119 | 109	44	374 | 342	76 | 69	37	314 | 287	58 | 53
55	65	550 | 503	145 | 132	47	392 | 359	93 | 85	39	327 | 299	70 | 64
60	68	572 | 523	168 | 154	50	411 | 376	115 | 105	42	340 | 311	83 | 76
65	72	590 | 540	196 | 179	53	424 | 388	130 | 119	44	351 | 321	98 | 90
70	76	609 | 557	223 | 204	56	438 | 401	151 | 138	47	360 | 329	113 | 103
75	80	622 | 569	253 | 231	59	450 | 411	175 | 160	49	368 | 336	129 | 118
80	84	633 | 579	284 | 260	62	460 | 421	197 | 180	52	375 | 343	145 | 132
85	88	643 | 588	317 | 290	66	468 | 428	218 | 199	54	385 | 352	164 | 150
90	91	649 | 593	348 | 318	69	475 | 435	241 | 220	57	388 | 355	180 | 164
95	95	652 | 596	381 | 348	72	479 | 438	265 | 242	60	391 | 358	198 | 181
100	99	652 | 596	414 | 378	75	480 | 439	288 | 263	62	389 | 356	216 | 198
105	103	650 | 594	448 | 410	79	481 | 439	315 | 288	66	392 | 358	238 | 218
110	107	647 | 591	477 | 436	82	478 | 437	339 | 310	68	392 | 358	250 | 229
115	112	636 | 582	512 | 468	85	472 | 432	364 | 333	71	388 | 355	268 | 245
120	115	626 | 572	541 | 494	89	467 | 427	386 | 353	74	384 | 351	285 | 260
125	120	611 | 559	574 | 525	92	458 | 419	410 | 375	76	380 | 347	297 | 272
130	124	595 | 544	602 | 550	95	451 | 412	431 | 394	79	373 | 341	315 | 288
135	128	579 | 530	627 | 574	98	441 | 403	452 | 413	82	364 | 333	330 | 301
140	132	558 | 510	653 | 597	102	420 | 384	472 | 431	85	356 | 325	343 | 313
145	136	532 | 487	677 | 619	105	407 | 372	492 | 450	88	346 | 317	356 | 325
150	140	507 | 463	700 | 640	109	389 | 356	510 | 466	91	334 | 305	369 | 337
155	144	479 | 438	720 | 658	112	367 | 335	525 | 480	94	320 | 293	379 | 347
160	148	450 | 412	738 | 674	116	349 | 319	538 | 492	98	302 | 276	390 | 357
165	153	418 | 382	751 | 687	119	327 | 299	551 | 504	101	286 | 261	400 | 365
170	157	388 | 355	762 | 697	123	301 | 276	562 | 514	103	273 | 250	407 | 372
175	161	354 | 324	772 | 706	126	280 | 256	571 | 522	107	255 | 233	413 | 378
180	165	321 | 293	779 | 712	130	257 | 235	577 | 528	109	240 | 219	417 | 381

ACCELERATION AND DECELERATION TRIALS

Acceleration and Deceleration Trials were conducted on HEALY to determine the distance (reach) and time required to achieve a steady ship speed after the ship operators have commanded a change in the ship's powering conditions. This information is important for safety considerations should the ship be required to rapidly change it's speed and position to avoid contact with another object. In the case of HEALY, acceleration characteristics are also important for icebreaking (ramming) operations. The propulsion plant limitations experienced during standardization trials did not impact the runs requiring the 100% ahead condition because the 100% condition was not sustained for a long enough time to cause problems.

ACCELERATION AND DECELERATION TRIALS PROCEDURES

Each acceleration/deceleration run begins by obtaining a steady ship speed on the approach course for the run. Some acceleration runs begin from the Dead-In-the-Water (DIW) condition and the approach speed is zero. Once the ship is steady at the specified conditions, propulsion plant commands are issued in an attempt to reach a new operating condition as quickly as possible. Figure 17 shows the typical path of the ship during an acceleration/deceleration maneuver.

The acceleration and deceleration runs were interspersed with two tactical circles so the ship track for each maneuver could be corrected for drift due to wind and water current. A tactical circle is conducted as close as possible in time and location to each acceleration or deceleration maneuver in order to determine the appropriate drift rate for correcting the ship's path during each run. The corrected ship path during each run was used to determine the distance (reach) and time required to achieve the desired steady condition following a particular engine order change.

The ship's Doppler Sonar Velocity Log (DSVL) was used to determine zero ship speed for the acceleration runs that begin with the ship in the DIW condition. Subsequent data analysis, i.e., the drift correction of the acceleration runs using drift vectors from the tactical circles interspersed with the acceleration/deceleration runs, indicated that one acceleration run began with an ahead approach speed of 0.9 knots rather than zero knots, while a second run had an astern approach speed of 0.9 knots.

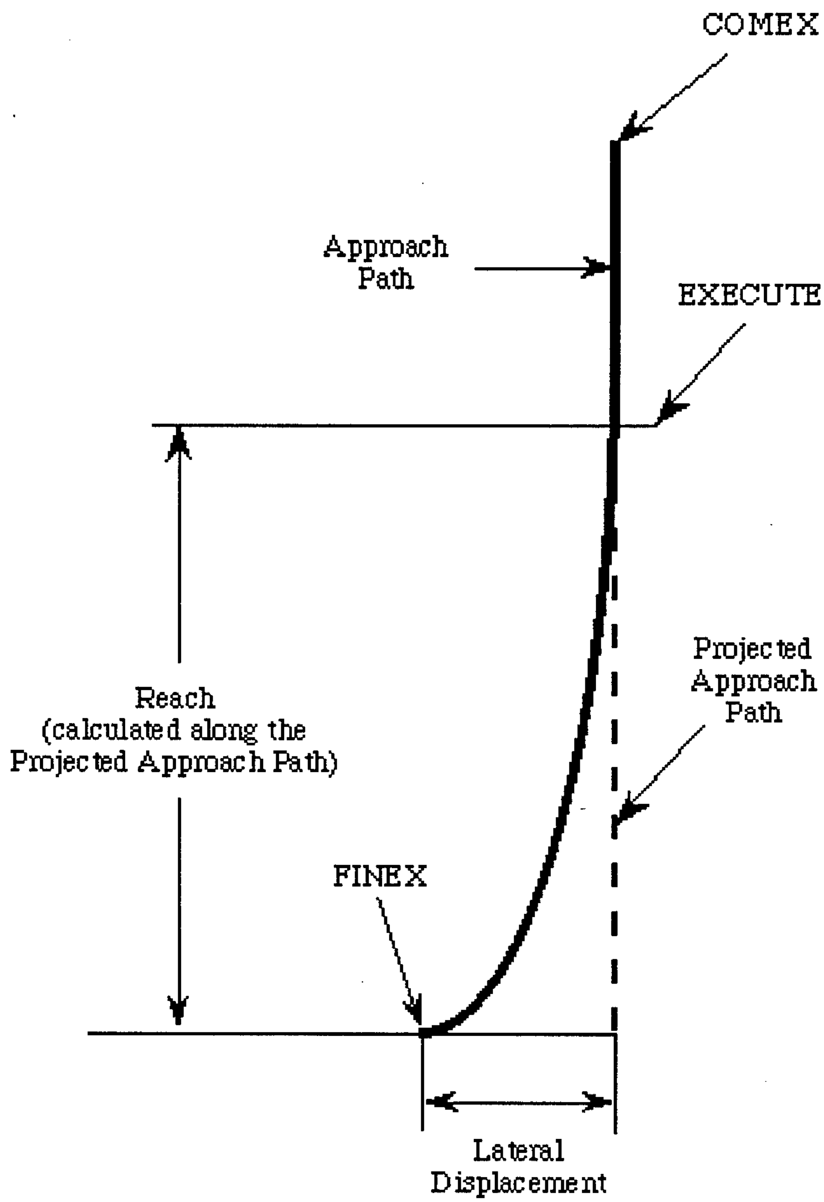

Fig. 17. Typical path of ship during an acceleration/deceleration run.

ACCELERATION AND DECELERATION TRIALS RESULTS

Figure 18 is a plot of the acceleration performance of HEALY when accelerating from the DIW condition using 50%, 75%, and 100% ahead power. Steady ship speeds of 10.4, 13.6, and 17.4 knots were achieved for the three acceleration runs. The highest steady speed, and the largest reach, 1985 yd (1815 m), resulted from the acceleration run using full power. The full power acceleration run resulted in HEALY achieving a steady speed in the least amount of time, 4.5 minutes. The run using 75% power resulted in a reach of 1765 yd (1614 m) in about 5.7 minutes.

Figure 19 illustrates the results of two deceleration runs using 50% astern power to stop. One run has an initial speed of 3 knots and one run has an initial speed of 10 knots. The deceleration run starting at 3 knots reached the DIW condition in 65 seconds and traveled 70 (yd) (64 m). The run beginning with an approach speed of 10.2 knots reached the DIW condition in about 160 seconds and traveled about 490 yd (448 m).

Figure 20 illustrates the stopping capability of HEALY when using 100% astern power. HEALY reached the DIW condition in 100 seconds and traveled 545 yd (498 m) when decelerating from a steady speed of 17.5 knots. When decelerating from 13.7 knots, HEALY reached the DIW condition in 90 seconds after travelling 380 yd (347 m). The smallest reach, 255 yd (233 m), and the least time to stop, 70 seconds, occurred when decelerating from 10.6 knots. Results of the acceleration and deceleration trials are summarized in Tables 16 and 17, respectively.

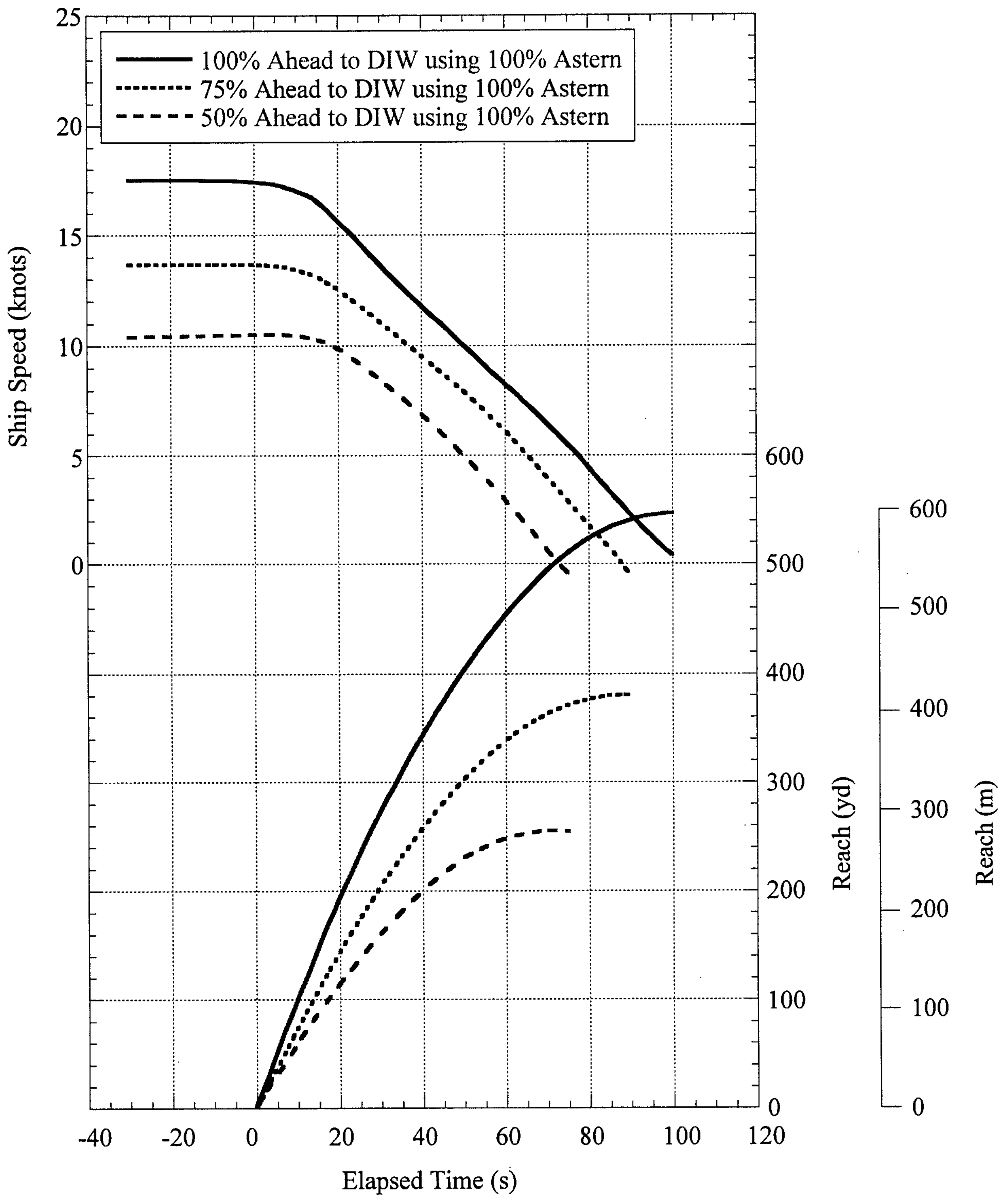

Fig. 18. USCGC HEALY (WAGB 20) acceleration trials results, DIW to steady ahead using 50%, 75%, and 100% power.

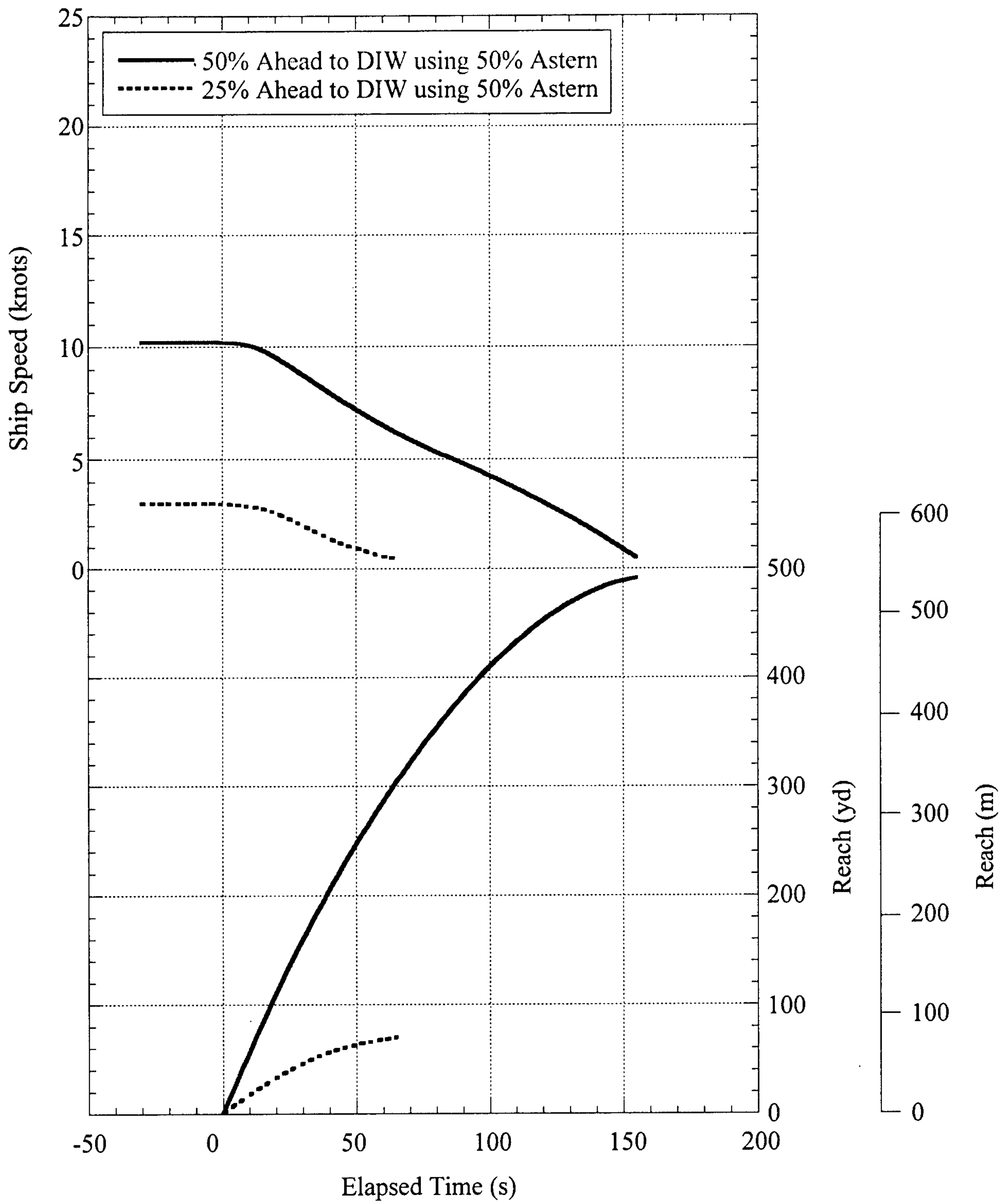

Fig. 19. USCGC HEALY (WAGB 20) deceleration trials results, various ahead speeds to DIW using 50% astern.

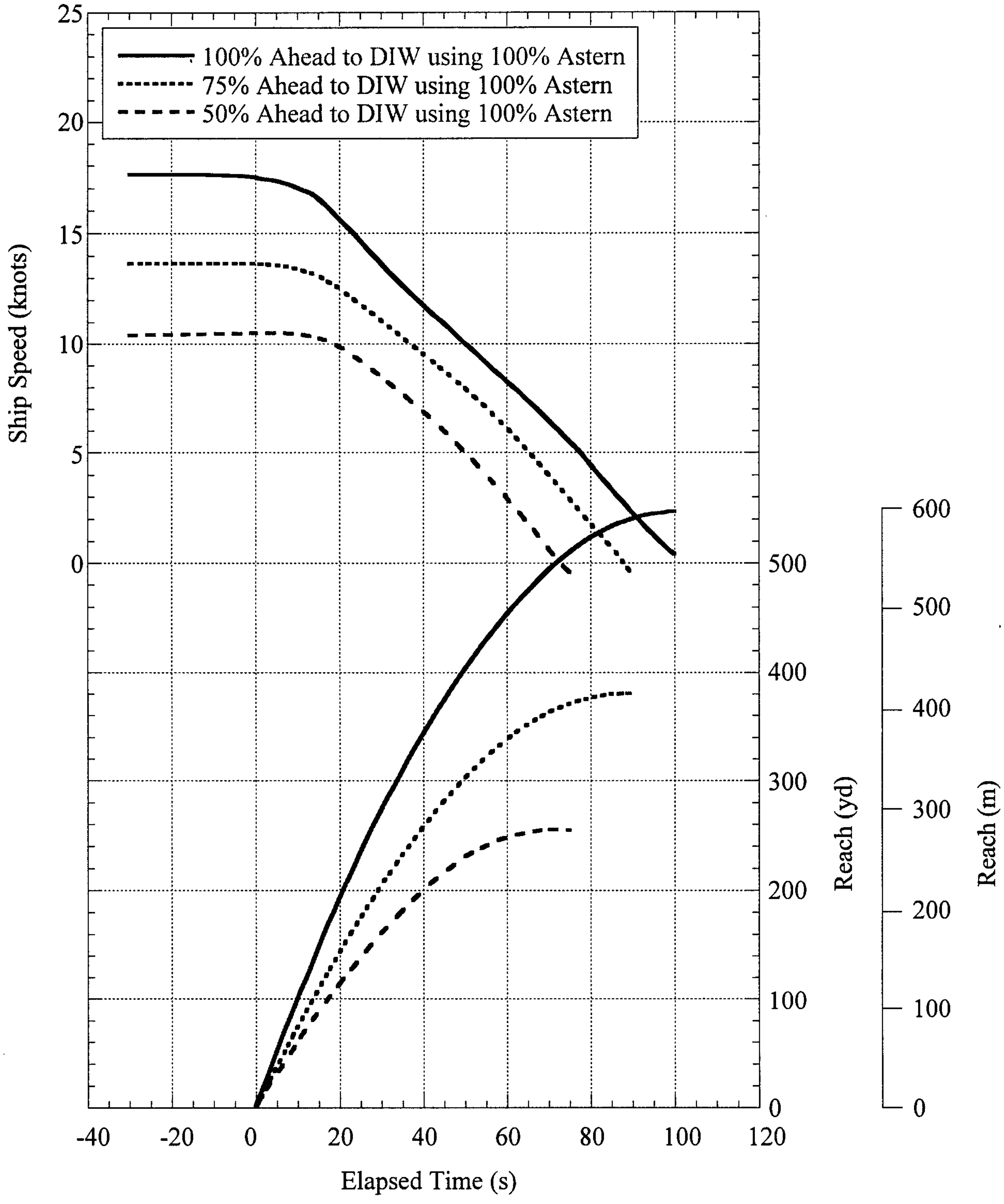

Fig. 20. USCGC HEALY (WAGB 20) deceleration trials results, various ahead speeds to 100% astern.

Table 16. USCGC HEALY (WAGB 20) acceleration trials results.

Run	Approach Engine Order	Terminal Engine Order	Approach Shaft Speed (rpm)	Terminal Shaft Speed (rpm)	Approach Ship Speed (knots)	Terminal Ship Speed (knots)	Terminal Time (s)	Terminal Reach (yd)	(m)
3210	DIW	50% Ahead	0	90	0.9	10.4	380	1660	1518
3230	DIW	75% Ahead	0	121	-0.25	13.6	335	1765	1614
3270	DIW	100% Ahead	0	160	-0.9	17.4	270	1985	1815

Table 17. USCGC HEALY (WAGB 20) deceleration trials results.

Run	Approach Engine Order	Terminal Engine Order	Approach Average Shaft Speed (rpm)	Terminal Average Shaft Speed (rpm)	Approach Ship Speed (knots)	Terminal Ship Speed (knots)	Terminal Time (s)	Terminal Reach (yd)	(m)
3221	50% Ahead	100% Astern	92	126	10.60	0.0	70	255	233
3240	75% Ahead	100% Astern	123	125	13.70	0.0	90	380	347
3300	100% Ahead	100% Astern	160	125	17.50	0.0	100	545	498
3290	25% Ahead	50% Astern	41	75	3.00	0.5	65	70	64
3260	50% Ahead	50% Astern	86	75	10.20	0.5	160	490	448

LATERAL STABILITY TRIALS

Lateral stability (spiral) maneuvers are typically performed to determine if a ship is directionally stable and to determine the ship's neutral rudder angle. Directional stability is characterized by the absence of turning rate hysteresis attributable to the direction of rudder travel.

LATERAL STABILITY TRIALS PROCEDURES

Verification that the ship turns the same to port and to starboard is achieved through a series of starboard to port, and port to starboard rudder deflections. Once a given angle of deflection is achieved, the ship is allowed to reach a steady rate of turn and then the rudder is eased to the next position. The series of rudder angles tested are achieved in order, first from large rudder angles to low rudder angles, and then from low angles to large angles.

Beginning with an approach speed of 12.5 knots, a steady rate of turn was achieved for each rudder angle listed in Table 18. Each rudder deflection was approached from the same direction and the helmsman did not hunt for exact rudder positions. During one maneuver, for example, moving from 19.5 degrees to 15 degrees actually resulted in a rudder position of 14.3 degrees, or slightly below the intended angle of 15 degrees. In this case the helmsman did not move the rudder back to 15 degrees, even when it was clear that the target value of 15 degrees had not been achieved.

The sea state was between 0 and 1 and the true wind speed was less than 10 knots at the time of the tests. The favorable weather conditions helped to obtain steady and repeatable rates of turn for both the large and the small rudder deflections.

LATERAL STABILITY TRIALS RESULTS

Results of the lateral stability trials are shown in Figure 21 and the relationship between yaw rate and rudder angle indicates the lack of significant hysteresis. Within the accuracy of the tests, the ship turns the same to port as to starboard, and is therefore directionally stable. The ship does appear to have a small neutral angle, of approximately 0.75 degrees right rudder.

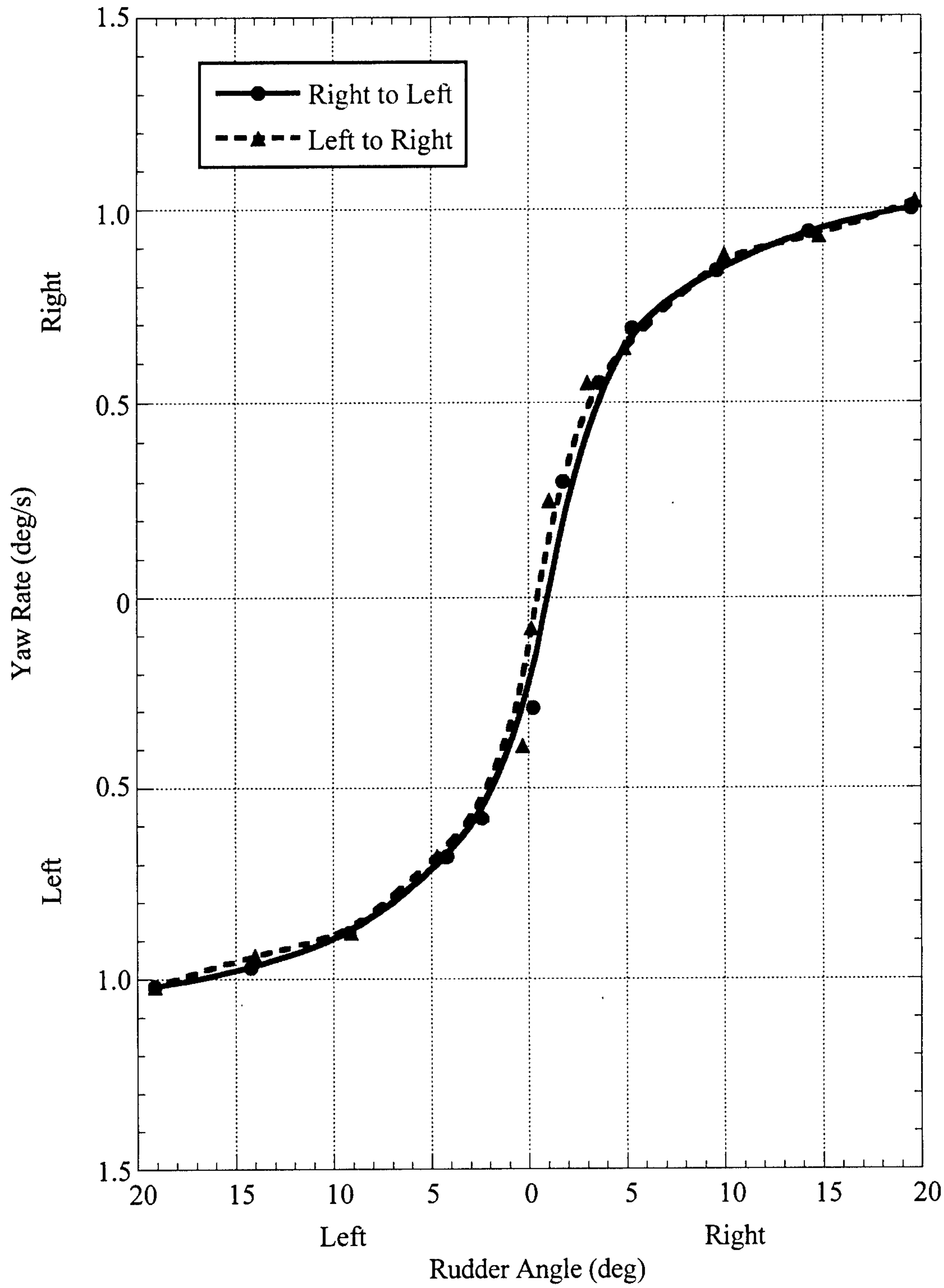

Fig. 21. USCGC HEALY (WAGB 20) lateral stability trials results, nominal 12.5 knots approach speed.

Table 18. USCGC HEALY (WAGB 20) lateral stability trials results, nominal 12.5 knots approach speed.

Right to Left			Left to Right	
Rudder Angle (deg)	Yaw Rate (deg/s)		Rudder Angle (deg)	Yaw Rate (deg/s)
19.5 R	1.00 R		19.1 L	1.02 L
14.3 R	0.94 R		14.0 L	0.94 L
9.6 R	0.84 R		9.1 L	0.88 L
5.3 R	0.69 R		4.7 L	0.68 L
3.6 R	0.55 R		2.4 L	0.57 L
1.8 R	0.30 R		0.3 L	0.39 L
0.3 R	0.29 L		0.2 R	0.08 L
2.4 L	0.58 L		1.1 R	0.25 R
4.2 L	0.68 L		3.0 R	0.55 R
9.2 L	0.88 L		4.9 R	0.64 R
14.2 L	0.97 L		10.0 R	0.88 R
19.1 L	1.02 L		14.8 R	0.93 R
			19.7 R	1.02 R

HORIZONTAL OVERSHOOT TRIALS

Horizontal overshoot maneuvers (zigzags) were accomplished on HEALY to determine the effectiveness of both right and left rudder throws in initiating and in checking turns. The procedures used for these tests, and the results obtained are discussed below.

HORIZONTAL OVERSHOOT TRIALS PROCEDURES

A horizontal overshoot test begins by obtaining a steady approach speed with the rudder amidships and the ship on a course that is directly into, or with, the direction of the existing true wind. This ensures that both port and starboard turns will be affected equally by the wind and the test results will not be biased.

Once the ship is steady on the base course, the rudder is smartly moved to the desired position, such as 10 degrees to starboard. When the ship's heading has changed by 10 degrees to the right of the base course, the rudder is quickly moved to 10 degrees to port. When the ship heading reaches 10 degrees to the left of the base course, the rudder is again shifted to 10 degrees to starboard. This procedure causes the ship to zigzag through the water and the run is complete when a minimum of two complete cycles of heading changes have occurred.

HORIZONTAL OVERSHOOT TRIALS RESULTS

Horizontal overshoot maneuvers conducted at 12.5 and 16.5 knots indicate that the two rudder angles tested, 10 degrees and 20 degrees, are effective in turning and in checking the turning of HEALY. Figures 22 through 25 illustrate the yaw checking ability of HEALY for the conditions tested. Ten degrees of rudder is not adequate to check the turning of some ships but that is clearly not the case for HEALY. Table 19 lists the turning characteristics determined during the horizontal overshoot maneuvers.

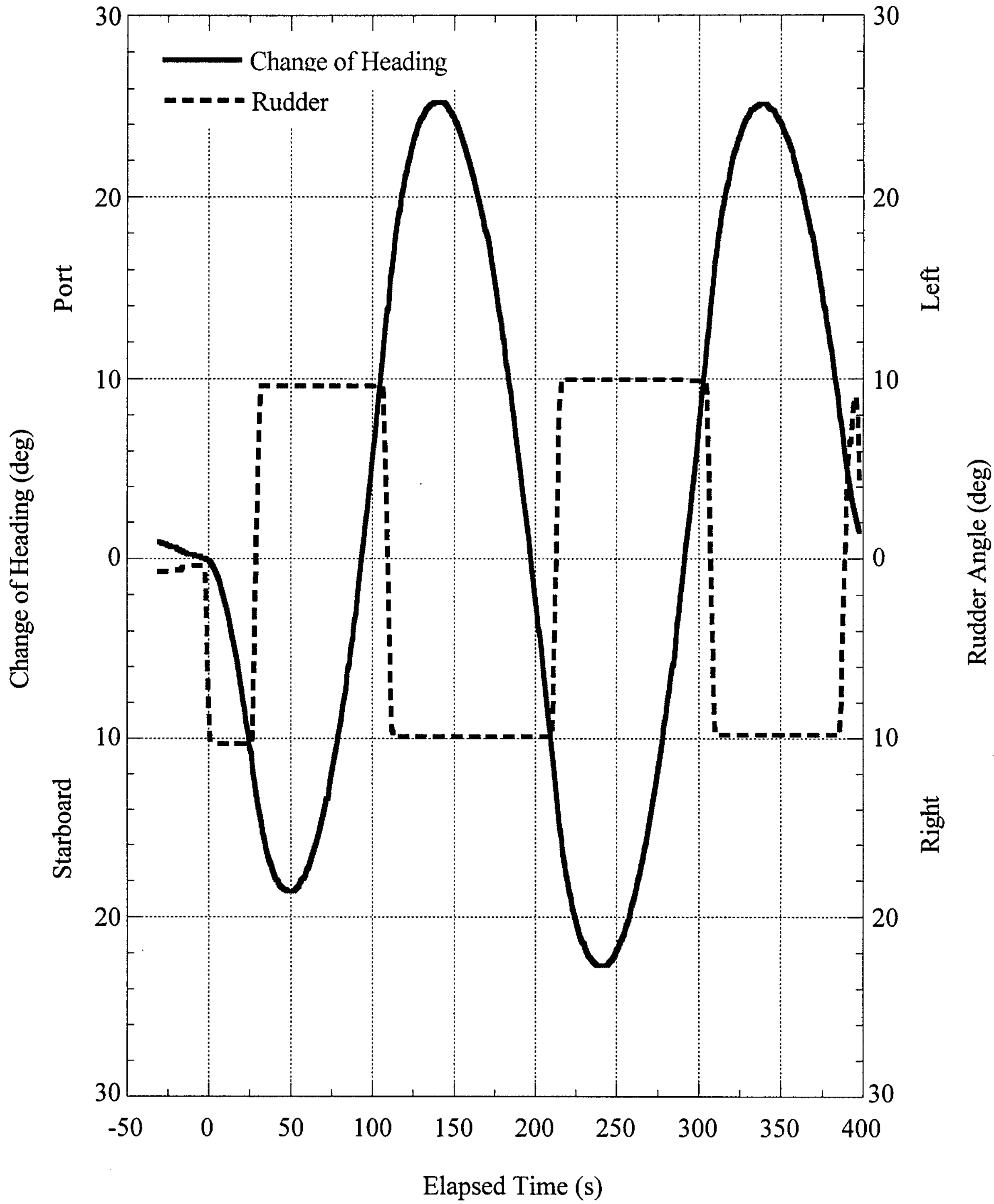

Fig. 22. USCGC HEALY (WAGB 20) horizontal overshoot trials results, nominal 12.5 knots approach speed, nominal 10 deg rudder angle, 26 August 1999.

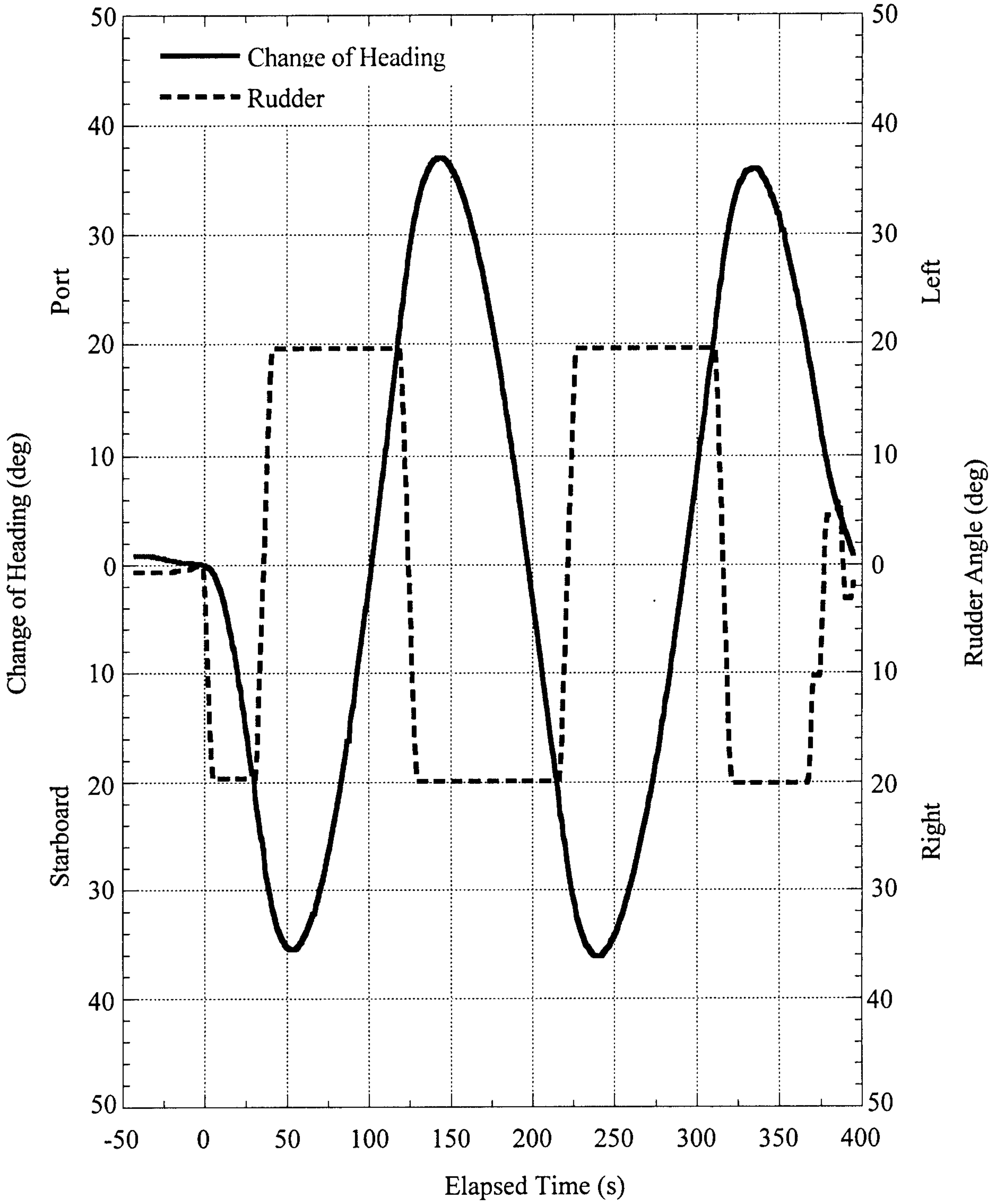

Fig. 23. USCGC HEALY (WAGB 20) horizontal overshoot trials results, nominal 12.5 knots approach speed, nominal 20 deg rudder angle, 26 August 1999.

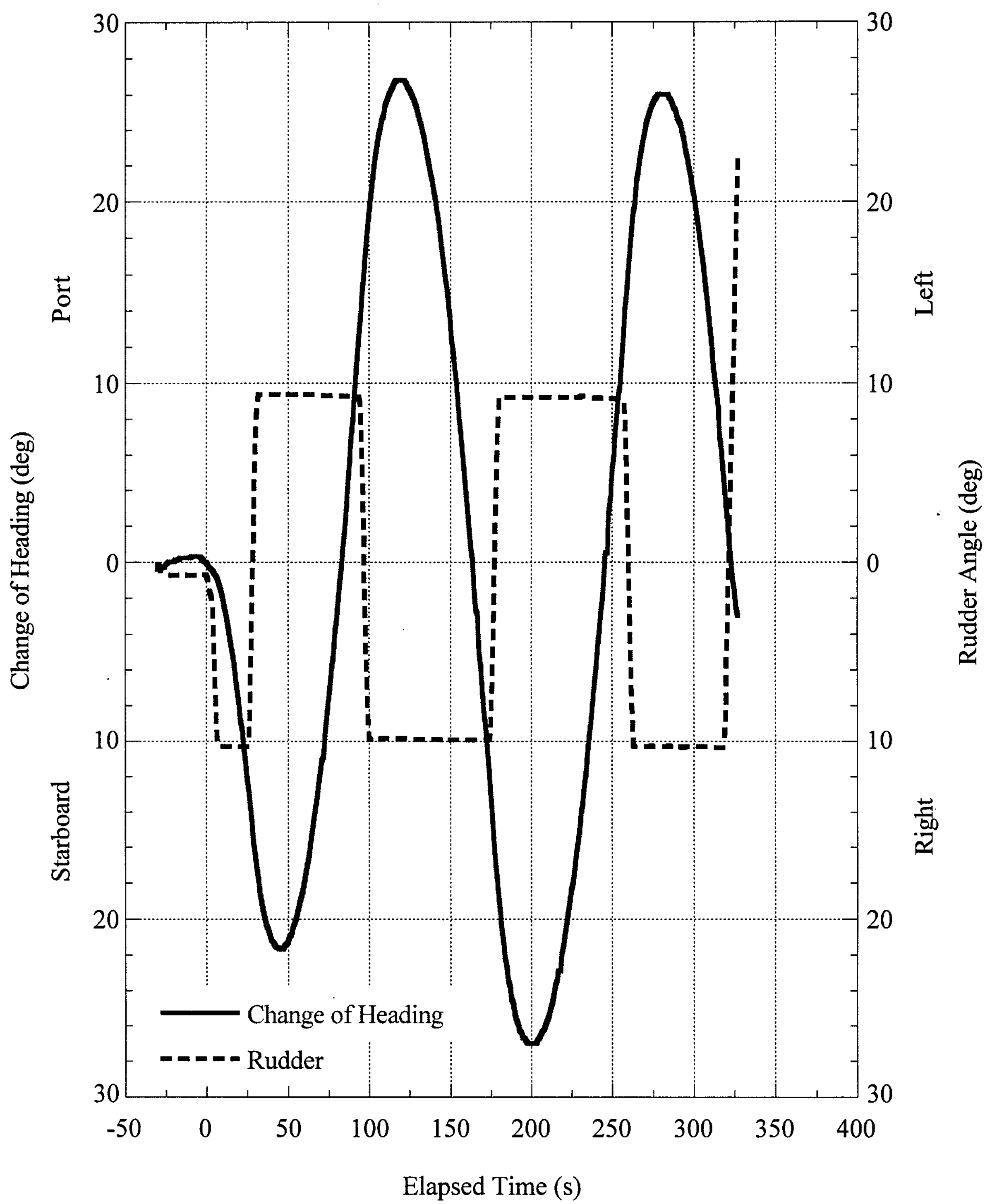

Fig. 24. USCGC HEALY (WAGB 20) horizontal overshoot trials results, nominal 16.5 knots approach speed, nominal 10 deg rudder angle, 26 August 1999.

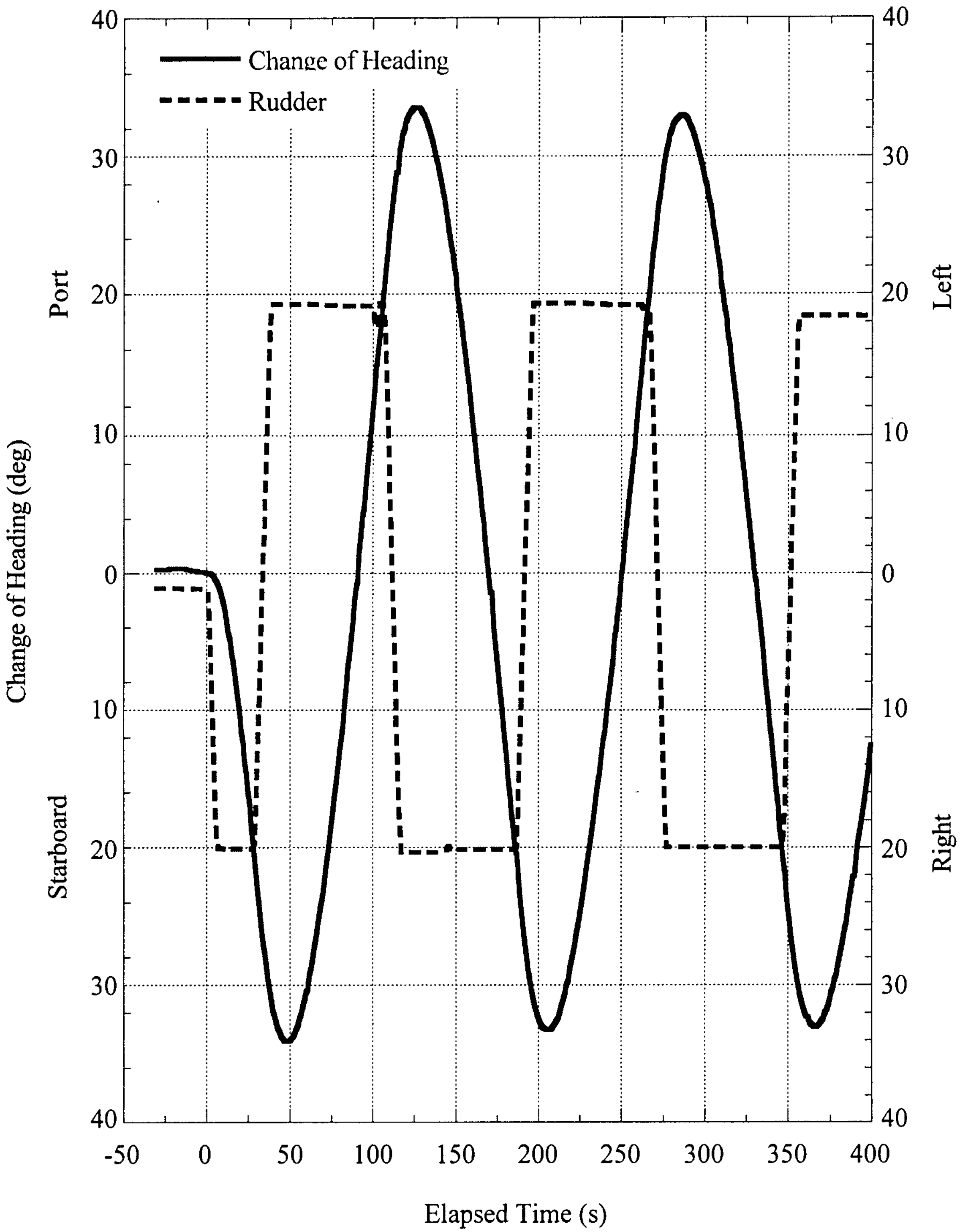

Fig. 25. USCGC HEALY (WAGB 20) horizontal overshoot trials results, nominal 16.5 knots approach speed, nominal 20 deg rudder angle, 26 August 1999.

Table 19. USCGC HEALY (WAGB 20) horizontal overshoot trials results.

Run Number	Nominal Approach Speed (knots)	Entrance Rudder Angle (deg)	Checking Rudder Angle (deg)	Change of Heading at Checking Execute (deg)	Maximum Heading Change (deg)	Maximum Overshoot Heading Change (deg)	Time 1st to 2nd Execute (s)	Time 2nd Execute to Max Overshoot (s)	Time 1st Execute to Max Overshoot (s)
4000	12.5	0.5 R	10.3 R						
		10.3 R	9.6 L	10.8	25.2	14.4	80	36	116
		9.6 L	9.9 R	9.6	22.7	13.1	103	32	135
		9.9 R	9.9 L	10.8	25.1	14.3	95	35	130
4010	12.5	0.8 R	19.7 R						
		19.7 R	19.6 L	21.4	37.0	15.6	88	25	113
		19.6 L	19.9 R	21.4	36.1	14.7	97	24	121
		19.9 R	19.6 L	20.0	36.0	16.0	94	25	119
4020	16.5	0	10.3 R						
		10.3 R	9.3 L	11.5	26.8	15.3	68	27	95
		9.3 L	9.9 R	11.5	27.0	15.5	81	27	108
		9.9 R	9.2 L	12.5	26.0	13.5	83	24	107
4030	16.5	0.8 R	20.1 R						
		20.1 R	19.2 L	24.3	41.9	17.6	78	21	99
		19.2 L	20.2 R	25.0	41.6	16.6	80	20	100
		19.2 L	19.2 L	24.0	41.2	17.2	80	21	101
		20.2 R	20.0 R	24.6	41.3	16.7	80	21	101

LOW SPEED CONTROLLABILITY TRIALS

The low speed controllability of a ship is determined by conducting zigzag maneuvers at very low ship speeds. Test procedures and the results of the low speed controllability maneuvers are discussed below.

LOW SPEED CONTROLLABILITY TRIALS PROCEDURES

Low speed controllability trials begin by obtaining a steady approach speed with the rudder amidships and the ship on a course that is directly into or with the existing true wind. This ensures that turns to the port or to the starboard will be affected equally by the wind, and the test results will not be biased.

Once the ship is steady on course, the rudder is smartly moved to the desired rudder angle, such as right 10 degrees. The rudder angle is maintained for 30 seconds and then moved to left 10 degrees and held for another 30 seconds. Thirty seconds later the rudder is moved to 0 degrees and the run is terminated. During the trials on HEALY this procedure was accomplished at steady speeds of 6, 5, 4, 3, and 2 knots for rudder angles of 10 degrees and 35 degrees.

LOW SPEED CONTROLLABILITY TRIALS RESULTS

The results of the low speed controllability runs indicate that rudder effectiveness is greatly reduced at ship speeds less than six knots. Figure 26 indicates that the ship can be slowly turned using a rudder angle of 10 degrees. At any speed less than six knots, however, the ship's turning cannot be effectively checked. This lack of checking capability is in contrast to the characteristics determined during the horizontal overshoot tests at the nominal speed of 12.5 knots.

Ship controllability is even further limited when a rudder angle of 35 degrees is used at speeds of six knots or less. Figure 27 indicates that turns can be initiated but cannot be effectively checked unless the initial ship speed is greater than six knots. Use of 35 degrees rudder causes the ship to initially turn at a higher rate, but the large rudder angle has the effect of causing a greater reduction in ship speed that further reduces ship controllability.

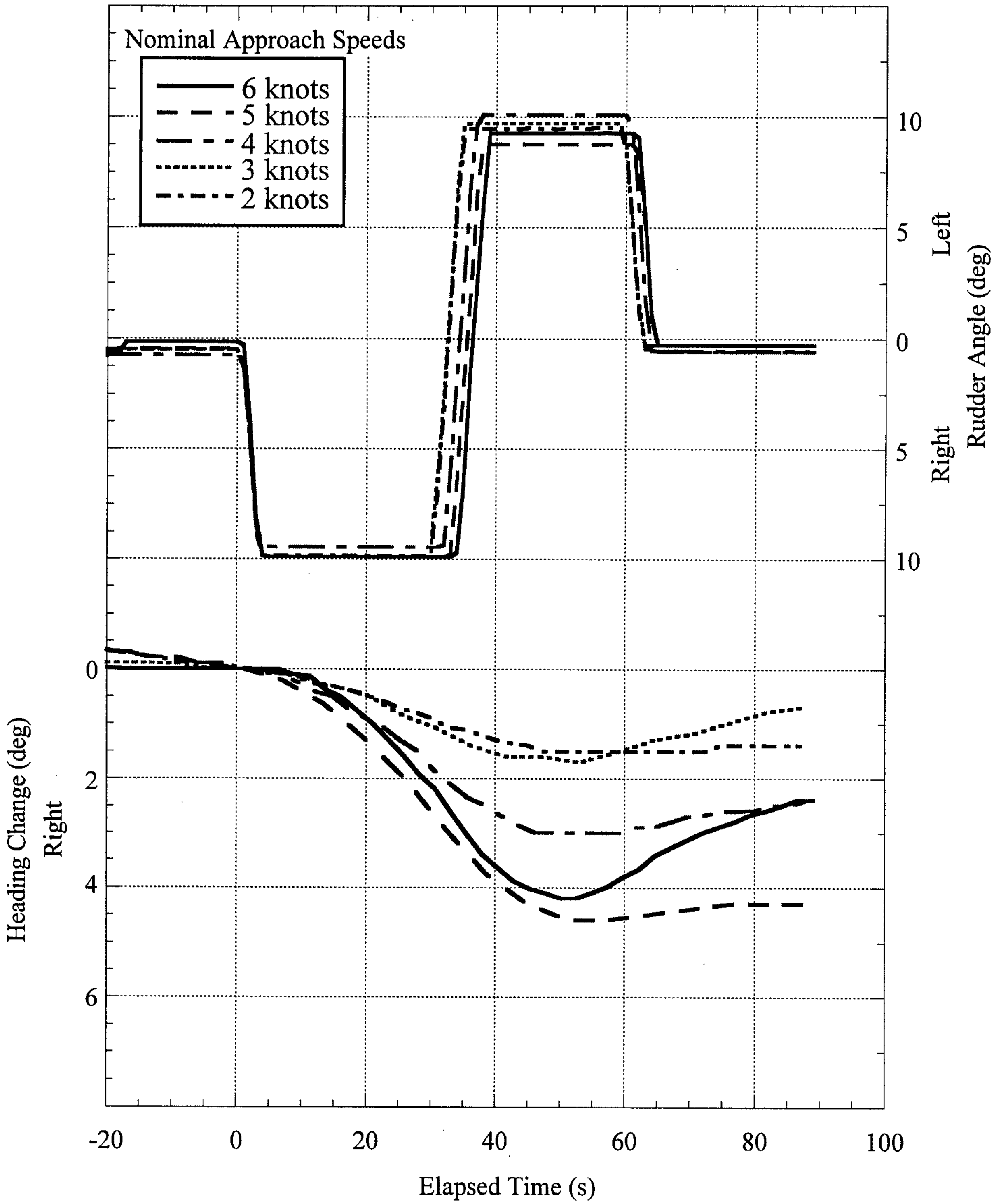

Fig. 26. USCGC HEALY (WAGB 20) low speed controllability trials results, nominal 10 deg rudder angle, 26 August 1999.

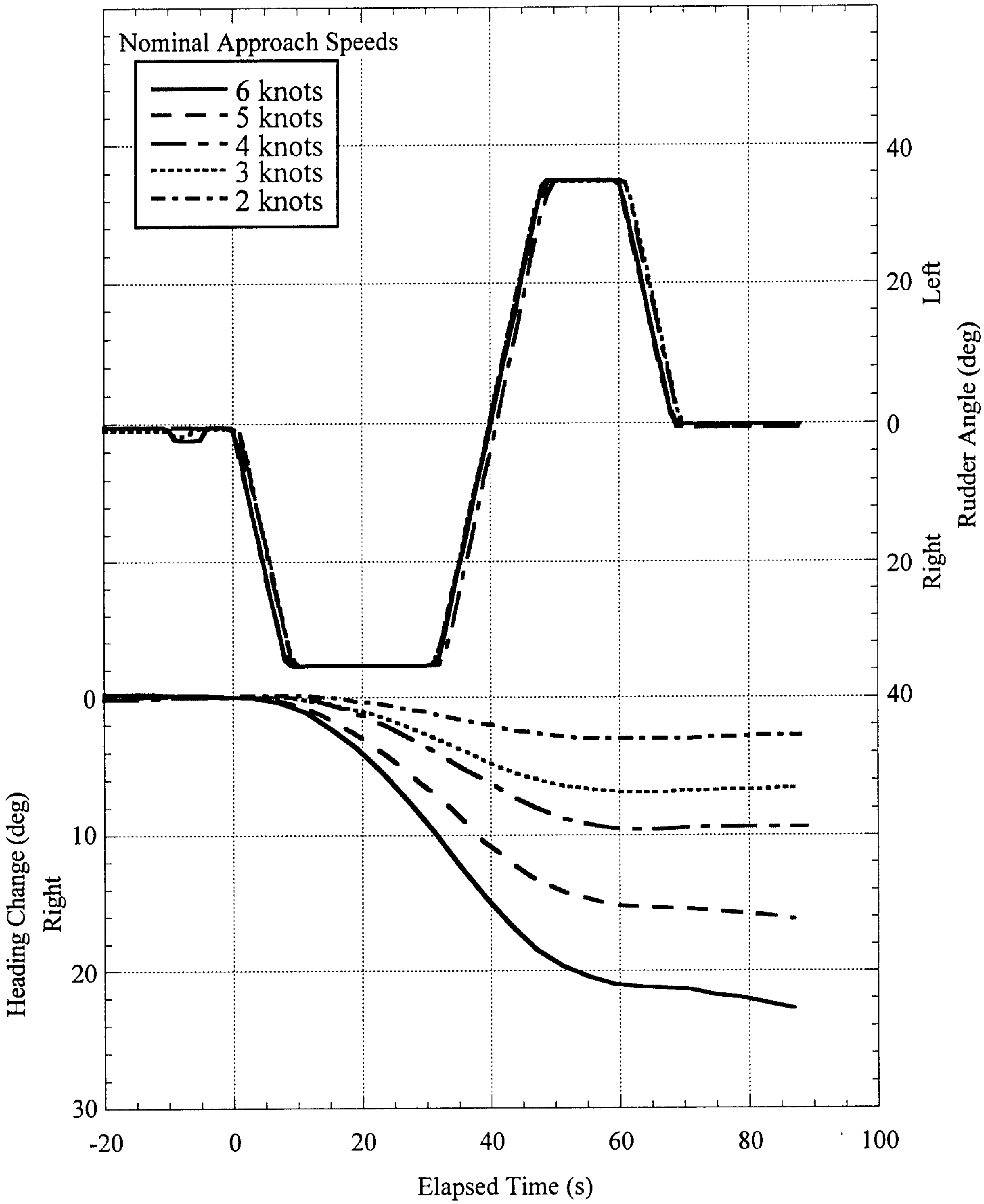

Fig. 27. USCGC HEALY (WAGB 20) low speed controllability trials results, nominal 35 deg rudder angle, 26 August 1999.

CONCLUSIONS

1. Standardization trials results indicated the maximum tested condition of 16.40 knots at a shaft speed of 148.4 rpm, total shaft torque of 725,000 lbf-ft (983,000 N-m), total shaft power of 20,500 hp (15,300 kW), and total fuel consumption rate of 10005 gal/hr (3,806 liters/hr). Due to propulsion plant limitations, standardization tests could not be conducted at conditions above 148 rpm.

2. For all ship speeds tested, HEALY has a tactical diameter of 3.1 ship lengths or less when using a rudder angle of 35 degrees. This meets the ship design criterion of a tactical diameter less than or equal to 3.5 times the ship length on the waterline (401.6 ft.).

3. HEALY has similar tactical characteristics whether turning to starboard or to port.

4. Lateral stability trials results indicate that HEALY is directionally stable.

5. The controllability of HEALY is significantly reduced at speeds below 6 knots.

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APPENDIX A: INSTRUMENTATION

INSTRUMENTATION INSTALLATION

Data collection and data analysis computers used during Performance Trials on HEALY were installed in the ship's Chart Room. The Chart Room provided a well-lighted, well-ventilated, and secure compartment that facilitated the data collection and analysis process. The trials team was provided with a key to the normally locked compartment and was given access to the desks and storage shelves also located in the Chart Room.

The Chart Room provided easy access to the various personnel in charge of ship trials, the ship Captain, Avondale Shipyard personnel, and Coast Guard personnel. This centralized location enabled all concerned trials personnel to communicate regarding test procedures, the need for changes in the schedule, and test results. Digital and/or analog signals from the Bridge, the Motor Room, the Generator Room, and the Boiler Room were therefore routed to the Chart Room.

Some signals were routed to the Chart Room via cables specifically installed for the trials. The majority of the signals, however, were transmitted to the Chart Room using the ship's fiber optic data network. Figure A.1. is a block diagram of the instrumentation used during the trials.

INTEGRATED BRIDGE SYSTEM AND GPS

A serial connection was made to the ship's Integrated Bridge System to obtain roll, pitch, heading, and relative wind velocity measurements. Additional signals from the Integrated Bridge System included outputs from the Doppler speed log and the ship's Global Positioning System (GPS). Sperry Marine personnel provided valuable assistance in making the necessary connections to the Integrated Bridge System.

The output of the ship's rudder angle repeater system was paralleled and input to a synchro-to-analog converter. The resulting direct current voltage output signals were then connected to the data collection computer.

In addition to the ship's GPS , NSWCCD installed a military keyed Precise Lightweight Global Positioning System Receiver (PLGR) on the ship's mast above the bridge. This receiver was installed in order to obtain the best accuracy possible (short of a differential system) from the GPS constellation. The output cable from the PLGR was routed down the mast trunk and into the Chart Room.

MOTOR ROOM

Torsionmeters were installed on the port and starboard shafts in the motor room to obtain a precise measure of shaft torque. Torsionmeters installed on HEALY consist of steel rings that clamp around each shaft to mechanically transfer shaft deflection to sensors that are bolted to the rings. Shaft deflection transferred to the sensors causes strain gauges within the sensors to produce a signal proportional to the magnitude of the shaft torque. The output signal is transmitted from the rotating torque sensors and is converted to a direct current voltage that is proportional to shaft torque based on the known shaft characteristics, i.e., modulus of rigidity, shaft outside diameter, and shaft inside diameter.

Torque calibration values used for HEALY are as follows:

	Port Shaft	Starboard Shaft
Outside Diameter (in)	23.672	23.667
Inside Diameter (in)	7.992	7.992
Modulus of Rigidity (psi)	11750000	11750000

A shaft speed measurement system was also installed on each main propulsion shaft. This system consists of 60 strips of infrared reflective tape attached to each shaft and an infrared light source/light sensor mounted adjacent to the tapes on the shaft. Each shaft revolution therefore produced 60 voltage pulses that were converted to a direct current voltage that was directly proportional to shaft speed. Both the torque and the shaft speed signals were then routed through an analog-to-digital (A/D) converter located in the motor room. The resulting digital signals were then routed to the Chart Room via the ship's fiber optic network. Shaft power was subsequently computed using the torque and shaft speed inputs.

GENERATOR ROOM

Calibrated turbine flowmeters were provided by, and installed by, Carderock Division, Naval Surface Warfare Center, Ship Systems Engineering Station, Philadelphia. Turbine flowmeters were installed on the supply and return sides of the four main diesel generators located in Generator Room Number 1 and Generator Room Number 2. Resistance temperature devices were also installed on the diesel generators in order to correct the fuel rates for the effects of temperature. The frequency outputs of these transducers were converted to direct current voltages and were routed to an analog-to-digital (A/D) converter located in the Engineering Control Center (ECC). The resulting digital signals were routed to the Chart Room via the ship's fiber optic network.

BOILER ROOM

Frequency-to-voltage (F/V) converters and an A/D converter were located in the Boiler Room to convert the outputs of fuel meters installed on Boiler Number 2. Digital signals representative of the boiler fuel rates and fuel temperatures were similarly routed to the Chart Room via the ship's fiber optic network.

DATA MONITORING AND ANALYSIS

An integrated data acquisition and analysis system located in the Chart Room was used for monitoring, recording and analysis of the trials data All of the measurements obtained during the Performance Trials were monitored real-time via flat panel monitors installed in the Chart Room as well as on the bridge. These displays were used to set the appropriate ship conditions for each run and to ensure that all instrumentation was operating properly. Upon completion of the run, the data was immediately analyzed and the results examined for use in determination of the success of the run.

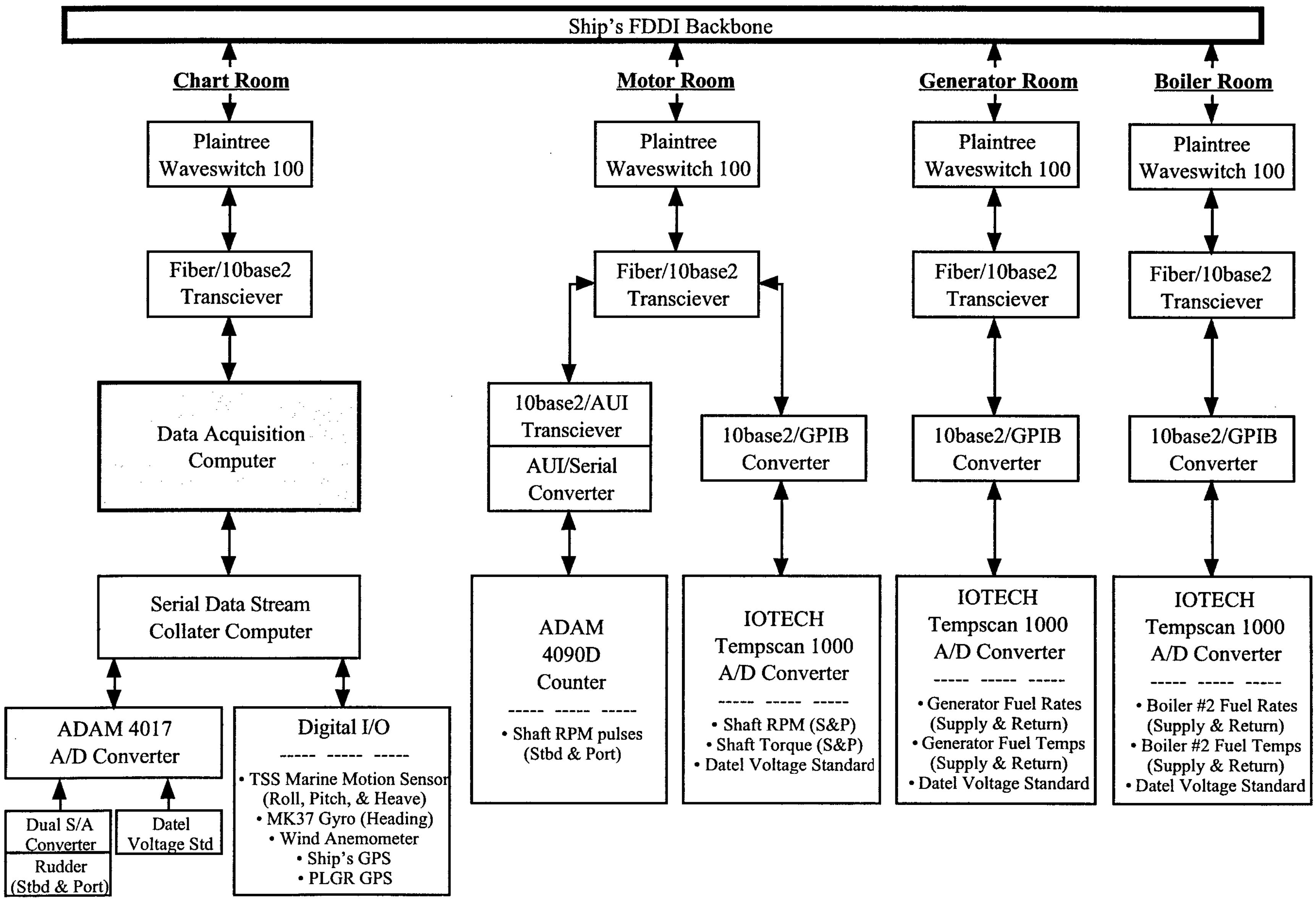

Fig. A.1. USCGC HEALY (WAGB 20) trials instrumentation diagram.

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APPENDIX B: MEASUREMENT UNCERTAINTY

INTRODUCTION

This appendix summarizes the instrumentation and the associated measurement uncertainties for sea trials conducted on HEALY. A more detailed uncertainty analysis of typical full scale sea trials measurements can be found in the CARDEROCKDIV report on uncertainty analysis of full-scale trials by E.H. Johnson [1]. A general discussion of uncertainty analysis may be found in "Experimentation and Uncertainty Analysis" by H.W. Coleman and W.G. Steele [2]. This analysis assumes that the repeatability of runs and standardization "spots" are the data of interest, so the uncertainty due to the scatter observed in any individual run is not considered. We are able to say with 95% confidence that the points which make up the standardization curves are accurate and repeatable within $\pm U_X$. (the total uncertainty of a reading X).

CALIBRATIONS

The scaling coefficients for measurements obtained from the ship's equipment were determined by aligning the raw output of each sensor with its corresponding digital or mechanical indicator reading. In the case of the rudder measurement, for example, the rudder was carefully positioned, and held, at numerous angles as indicated by the rudder reference scale (quadrant) located on the rudder stock in aft steering. The voltage outputs from the rudder sensor were recorded and equated to positions of the quadrant pointer. At the completion of the alignment, a linear regression curve fit is applied to generate the gain and zero values.

The shaft torsionmeters were calibrated in a laboratory calibration stand prior to being shipped to the installation site. The torque sensors were deflected by known amounts equivalent to torque values between zero and 120 percent of the design full-scale torque. The curve fit technique was used to correlate the known torque values with the corresponding sensor outputs. After installation, jackshafts are conducted to set the zero on the torsionmeters.

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1. Johnson, Erik H., "Uncertainty Analysis of Standardization Trials on a Navy Fleet Oiler," CARDEROCKDIV/HD-1428-01 (Sept 1993).
2. Coleman, Hugh W., and W. Glenn Steele, "Experimentation and Uncertainty Analysis for Engineers," John Wiley & Sons, Inc. (1989).

The shaft speed measurement system was calibrated by injecting several precisely known frequencies into the frequency-to-voltage (F/V) converters used to produce a direct current voltage. The curve fit technique was then used to correlate the known frequencies (shaft speed) with the corresponding voltage outputs.

The summary results for the uncertainty of the signals measured during the trials on HEALY are shown in Table B.1.

Table B.1. USCGC HEALY (WAGB 20) measurement uncertainties.

Signal Name	Units	Bias Error	Precision Error	Total Uncertainty	Maximum Calibrated Value	Percent Uncertainty Relative to Maximum Value
Rudder	deg	± 0.171	± 0.426	± **0.459**	35.0	1.31%
Shaft Speed - Stbd (F/V)	rpm	± 0.435	± 0.383	± **0.580**	284.0	0.20%
Shaft Speed - Port (F/V)	rpm	± 0.113	± 0.697	± **0.706**	284.0	0.25%
Shaft Speed - Stbd (Counter)	rpm	± 0.119	n/a	± **0.119**	n/a	n/a
Shaft Speed - Port (Counter)	rpm	± 0.119	n/a	± **0.119**	n/a	n/a
Shaft Torque - Stbd	lbf-ft	± 2,477	± 5,436	± **5,974**	794,795	0.75%
Shaft Torque - Port	lbf-ft	± 2,514	± 1,631	± **2,997**	-794,795	0.38%
Generator 1 Fuel Rate - Supply	gpm	± 0.154	± 0.372	± **0.40**	30.0	1.34%
Generator 1 Fuel Rate - Return	gpm	± 0.162	± 0.418	± **0.45**	30.0	1.49%
Generator 2 Fuel Rate - Supply	gpm	± 0.201	± 0.344	± **0.40**	30.0	1.33%
Generator 2 Fuel Rate - Return	gpm	± 0.168	± 0.387	± **0.42**	30.0	1.41%
Generator 3 Fuel Rate - Supply	gpm	± 0.177	± 0.436	± **0.47**	30.0	1.57%
Generator 3 Fuel Rate - Return	gpm	± 0.182	± 0.455	± **0.49**	30.0	1.63%
Generator 4 Fuel Rate - Supply	gpm	± 0.141	± 0.394	± **0.42**	30.0	1.39%
Generator 4 Fuel Rate - Return	gpm	± 0.159	± 0.445	± **0.47**	30.0	1.58%
Generator 1 Fuel Temp - Supply	deg F	± 1.650	± 0.139	± **1.66**	150.0	1.10%
Generator 1 Fuel Temp - Return	deg F	± 1.852	± 0.161	± **1.86**	150.0	1.24%
Generator 2 Fuel Temp - Supply	deg F	± 1.801	± 0.158	± **1.81**	150.0	1.21%
Generator 2 Fuel Temp - Return	deg F	± 1.722	± 0.182	± **1.73**	150.0	1.15%
Generator 3 Fuel Temp - Supply	deg F	± 1.795	± 0.153	± **1.80**	150.0	1.20%
Generator 3 Fuel Temp - Return	deg F	± 1.678	± 0.183	± **1.69**	150.0	1.13%
Generator 4 Fuel Temp - Supply	deg F	± 1.714	± 0.119	± **1.72**	150.0	1.15%
Generator 4 Fuel Temp - Return	deg F	± 1.773	± 0.176	± **1.78**	150.0	1.19%
Roll	deg	± 0.325	± 0.459	± **0.56**	30.0	1.87%
Pitch	deg	± 0.288	± 0.821	± **0.87**	30.0	2.90%
Heading	deg	± 0.297	± 1.336	± **1.37**	360.0	0.38%
Wind Speed	knots	± 5.0	± 3.5	± **6.10**	100.0	6.10%
Wind Direction	deg	± 0.5	± 1.1	± **1.21**	360.0	0.34%
Doppler Speed	knots	± 0.4	± 0.6	± **0.72**	40.0	1.80%
X position	yd	± 1	± 3	± **3**	n/a	n/a
Y position	yd	± 1	± 3	± **3**	n/a	n/a

SAMPLE UNCERTAINTY CALCULATION

The process of calculating measurement uncertainty is demonstrated in Tables B.2. and B.3. using the starboard shaft speed signal as an example. This particular signal was measured using an inferred light sensor and the frequency-to-voltage converter embedded within the starboard shaft's torsionmeter system. The voltage was then acquired using an A/D converter located in the Motor Room.

Table B.2. USCGC HEALY (WAGB 20) Shaft Speed – Stbd (F/V) signal calibration results.

Ship	USCGC HEALY (WAGB 20)		
Channel Name	Shaft Speed - Stbd (F/V)		
Calibration Date	11-Feb-99		
Output Voltage (volts)	Engineering Units, (rpm)	Curve Fit, (rpm)	Difference Squared
0.001	0.00	-0.48	0.23
1.384	41.00	41.04	0.00
2.726	81.00	81.34	0.11
4.080	122.00	121.99	0.00
5.615	168.00	168.08	0.01
6.773	203.00	202.85	0.02
8.141	244.00	243.92	0.01
9.478	284.00	284.07	0.00
8.141	244.00	243.92	0.01
6.773	203.00	202.85	0.02
5.615	168.00	168.08	0.01
4.079	122.00	121.96	0.00
2.726	81.00	81.34	0.11
1.384	41.00	41.04	0.00
Standard error of estimate (SEE), rpm		===>	0.21
Bias of curve fit, rpm		===>	0.42
Slope, rpm/volt		===>	30.0253
Intercept, rpm		===>	-0.5123
Intercept, -volts		===>	0.0171
Coefficient of determination (R^2)		===>	1.0000
Variance, rpm		===>	0.0385
Standard Deviation, rpm		===>	0.2036
Maximum Voltage (volts)		===>	9.478
Maximum engineering unit, rpm		===>	168.000

Table B.3. USCGC HEALY (WAGB 20) Shaft Speed – Stbd (F/V) uncertainty calculations.

Ship	USCGC HEALY (WAGB 20)		
Channel Name	Shaft Speed - Stbd (F/V)		
Calibration Date	11-Feb-99		
Maximum Calibrated Engineering Unit	284.00		
Corresponding Maximum Voltage	9.478		
Sources of Bias Error	**Variable**	**Units**	**Error**
(1) Linear speed to rotational speed	Bls	rpm	± 0.07
(2) Frequency-to-analog conv. during calibration and acquisition	Bf/a1, f/a2	rpm	± 0.060
(3) Analog-to-digital conversion during calibration and acquisition	Ba/d1, a/d2	rpm	± 0.020
(4) Curve fit	Bcf	rpm	± 0.420
(5) Total Bias Limit, RMS (1) through (4)	Bn	rpm	± 0.435
Sources of Precision Error			
(6) Repeatability index (standard deviation of the means)	Pnr	rpm	± 0.009
(7) Process unsteadiness, 1.96*(mean of the standard deviations)	Snp	rpm	± 0.383
(8) Total Precision Limit, RMS (6) and (7)	Pn	rpm	± 0.383
(9) Total Uncertainty, RMS (5) and (8)	Un	rpm	± 0.580

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